DESIGN, FABRICATION AND CHARACTERIZATION OF DOUBLE SLOPED SOLAR STILL FOR HOUSEHOLD USES IN KILIFI COUNTY USING LOCALLY AVAILABLE MATERIALS

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Design, Fabrication and Characterization of Double Sloped Solar still for Household uses in Kilifi County using locally available materials

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A thesis submitted in partial fulfilment for the Degree of Master of Science in Energy Technology in the Jomo Kenyatta University of Agriculture and Technology

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DECLARATION

This thesis is my original work and has not been submitted for a degree in any other University.

Signature …………………………………… Date ……………………………….

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DEDICATION

This thesis is dedicated to my Mother, Wife, daughters and brother who are a source of my encouragement and inspiration.

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NOMENCLATURE AND ABBREVIATIONS

CBK	-	Central Bank of Kenya
CDM	-	Clean Development Mechanism
CER	-	Certified emission rates
CPL	-	Cost per liter
KWh	-	Kilo Watt Hour
KSH	-	Kenya Shillings
GHG	-	Green House Gases
USD	-	United State Dollar
WHO	-	World Health Organization
LCC	-	life cycle cost
NPV	-	Net present value
SIR	-	Saving to Investment Ratio
IRR	-	Internal rate of return
SP	-	Simple pay back
KEBS	-	Kenya bureau of standards
EC	-	Electrical conductivity
L	-	Latent heat
T	-	Temperature
CRF	-	Capital Recovery Factor
E	-	Efficiency
A	-	Area of the solar still
Q	-	Daily output of solar still
G	-	Daily/Annual global horizontal solar radiation
PVC	-	Poly Vinyl Chloride
PPM	-	parts per millions
PPT	-	parts per thousands
SOK	-	Survey of Kenya
NTU	-	Nephelometric Turbidity Units
Rsq	-	correlation factor
TDS	-	Total Dissolved Solids

SFF	-	Sinking Fund Factor
ASV	-	Annual Salvage Value
FAC	-	First Annual Cost
P	-	Principal value/Present capital cost
M	-	Annual productivity
AC	-	Annual cost
AMC	-	Annual maintenance and operation cost
I_o	-	Initial capital cost
F	-	Running cost
i	-	Interest rate
t	-	Time in years
n	-	Number of years
ϕ	-	Latitude
	-	Inclination angle /slope
^{0}	-	Degree
^{0}C	-	Degree Celcius
€	-	Euro
t-CO2e	-	Tonne of CO_2 equivalent

ABSTRACT

Kilifi County, Kenya has encountered persistent water problems due to many factors like rapid population growth, poor maintenance of existing water supply networks, water salinity due to seawater intrusion, pollution from numerous pit latrines and septic tanks in the towns, high levels of humidity and temperature which causes dehydration to the residents. Solar energy is a clean, unlimited and very economic source of energy available to residents free of charge. Sea water and brackish water is available in Kilifi due to its proximity to the Indian Ocean and high water table levels. Solar still uses the principle of evaporation and condensation to produce distilled water. In an attempt to find sustainable solutions, a low cost double sloped solar still is designed, built and characterized based on Kenyan climatic condition using locally available materials. The designed solar still has a basin area of $1m^2$and glass cover inclined at 15^0 with an orientation in the north-south direction. Materials used for fabrication were block board, normal window glass of 4 mm and damp proof polythene paper which are all locally available. Experimental investigation on solar still was carried out to examine the quantity and quality of water under Kilifi county climatic conditions. Ambient temperatures, solar irradiation, relative humidity and water output were recorded at an interval of an hour from 8 am to 4 pm and cumulatively at 8 am from 4 pm to 8 am the following day. Data was analyzed using Microsoft excel and an efficiency of 12-20% was found with a correlation factor of more than 99% between the solar irradiation and solar still water output. Water samples were analyzed for physical, chemical and bacteriological parameters and the results obtained agreed with the standard values as prescribed by WHO and Kenya water standards KS 05-459 part 1:1996. Fabrication cost was found to be Kshs 9,350 with economic analysis showing the project as an economic viable and feasible project with high IRR, SIR, positive NPV and a short payback period of 195 days. The solar still was found to produce safe and clean water at a cheap cost of around Kshs 4.89 per litre and thus recommended for use in the local households.

CHAPTER ONE

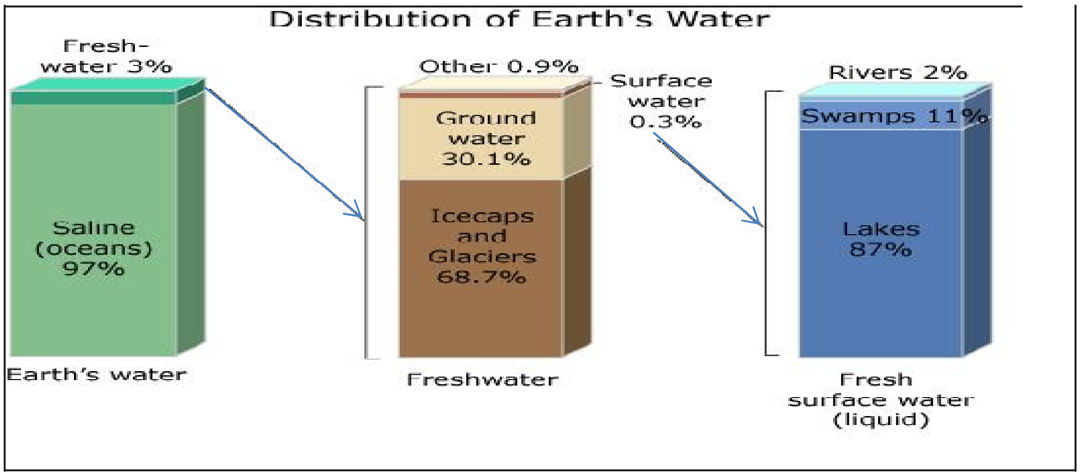
INTRODUCTION

1.1 Global water scenario

Worldwide, eight out of ten people in rural area lack access to an improved drinking water source, and 780 million people do not have access to an improved water source according to the World Health Organization (WHO) report of 2015 (WHO, 2015). Access to safe drinking water is important on all levels; global, national, regional and local. Estimates show that investments in water supply and sanitation give economic benefits, increased health effects and reduced health care cost, and thereby outweigh the investment costs (WHO, 2011).

Seckler (2001), argues that water scarcity is now the single greatest threat to human health, environment and global food supply. The 2009 World Water Development report (WWDR, 2009) revealed that nearly half of the global population will be living in regions of high water stress by 2030 (WWDR, 2009). If population and consumption trends persist, it is estimated that the demand for water will surpass its availability by 56% (World Water Organization, 2010) and 1.8 billion people will be living in regions of water scarcity by 2025 (UN News Service, 2009). This situation is exacerbated by the fact that developing countries, already experiencing water stress, often have the highest population growth rates bringing more people into a region that already cannot support them (World Water Assessment Programme, 2009).

Approximately 71% of the world is covered by water yet fresh water scarcity is one of the worst problems the world is faced with (WWDR, 2009). However fresh water makes up only 3% of the water available on the planet and much of it is locked in glacier and ice caps as indicated in figure 1.1.



Source: http//ga.water.usgs.gov/edu/waterdistribution.html accessed July 2012

Figure 1.1: World Water Distributions, 2012

Africa though has 11% of the world's waters; it has a better water balance since it has 13% of the world's population (UNESCO/IHP, 2001). However, millions of Africans are faced with severe water shortages due to uneven water distribution, poor water infrastructure networks and lack of good political will.

In Kenya, about 43% of Kenya's population has access to clean and improved drinking water (World Bank, 2010) and is classified as a water scarce country (Kenya Water Report, 2005).Water scarcity may be due to drought, poor management of the water supply, under-investment, unfair allocation of water resources, rampant deforestation, pollution of water supply by untreated sewage and huge population.

1.2 Kilifi County Water Scenario

Kilifi county is located North East of Mombasa and has a population of 1,109,735 people covering an area of 12,609.7 km^2 (Survey of Kenya, 2012). The County has encountered persistent water problems due to many factors like rapid population growth and poor maintenance of existing water supply networks. Although the area is geologically rich in groundwater which is often seen as an option, exploitation is limited due to salinity from seawater (Musingi *et al.,* 1999). Ground water exploitation is also curtailed by pollution from numerous pit latrines and septic tanks in the towns.

1.3 Solar Desalination as a solution to water crisis

Sea water desalination has been considered as a long-term freshwater source (Argaw, 2001). It is considered as a viable solution to drinking water all over the world. According to the statistics from the international desalination association (2008), about 17% of global desalination takes place in Saudi Arabia, followed by United Arab Emirates 13%, USA 13%, Spain 8%, Kuwait 5%, China 5%, Qatar 3%, Japan 2% and Australia 2%. Other countries accounts for the remaining 29% of global desalination capacity (Al-shuaib *et al.,* 1999).

Kilifi has an outstanding solar energy potential of average 19.8 MJ/m^2/day and maximum of 21.6 MJ/m^2/day during hot season when fresh water demand is high hence using solar energy to solve water scarcity is a justified option (Kenya meteorological department, 2018). Solar energy is a clean, unlimited and very economic source of energy available to residents free of charge. Sea water and brackish water which are salty are available in large quantities in Kilifi County due to its proximity to the Indian Ocean and high water table levels (Musingi *et al.*, 1999).

1.4 Statement of the problem

Freshwater is one of the scarce resources in the world which accounts only for around 3 percent of global water, the rest is saline water. The World Health Organization recommends that an individual should consume at least two liters of fresh water daily. The water scarcity problem is growing worse as the world's population grows and water supplies need to be increased at household levels. This is not an exceptional case for Kilifi residents who have been suffering for many years because of the non-availability of safe and clean drinking water. Kilifi County is a hot and humid region. This climate causes dehydration to the residents and thus there is need for sustainable, fresh, clean and safe drinking water.

In order to address water challenges, the study aims to find a lasting solution using solar energy which is available but not well harnessed in the area.

1.5 Justification of the study

Water is available in plenty in the Indian Ocean but the challenge is that it cannot be used for drinking. It has been revealed that more than 50% of all the diseases reported in the county are associated with lack of access to clean water and inadequate waste water management (Munga, 2002). Thus there is need of coming up with methods of getting clean drinking water.

Although setting up a county desalination plant is the best solution to the water crisis, it is capital intensive and takes time to construct. The persistent water problems, national grid power failures in Kilifi County calls for the residents to take care of their water needs at the household level and stop relying on water service providers who fails to supply clean water.

Other towns and cities that have carried out solar water desalination process are Baghdad in Iraq, California in United State of America and Faryab in Afghanistan which used solar stills for water desalination (Kolstad, 2014). In Baghdad, three solar stills were tested. All had black basins, and two of the stills had additionally jute wicks and in Faryab three solar still types namely single slope, double chamber, double sloped solar still and wick type solar still were tested and evaluated (Kolstad, 2014). The solar stills were found to be approximately 30 percent efficient and promising solution to water shortages (Al-Karaghouli *et al.*, 1995).

1.6 Hypothesis

There is no relationship between solar irradiation during the day and the clean water output from the double slope solar still.

1.7 Objectives

The main objective of this study is to design, fabricate and characterize a cost efficient double slope solar still using locally available materials in Kilifi County for small scale household use.

1.7.1 Specific Objectives

1. To design and fabricate double sloped solar still using 4 mm thickness glass, block board, damp proof polythene paper and pipes which are locally available,
2. To characterize the double slope solar still,
3. To carry out economic analysis on the designed and fabricate double slope solar still,
4. To carry out water quality assessment.

1.8 Study scope

The study aims at providing solutions to water crisis in Kilifi County by use of solar stills to desalinate brackish groundwater and seawater. The study examined factors that influence the efficiency of the solar stills such as materials, design and climatic conditions. The cost was also considered.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

All desalination methods require fossil fuel or electrical energy but solar distillation is a process that can be used to produce fresh water by use of the heat from the sun directed into a simple water purifying equipment. The equipment is commonly called a solar still (Tiwari & Tiwari, 2007). Solar desalination could be one of the most successful applications of solar energy in most of the hot climate countries having limited resources of fresh water (Argaw, 2001).

Solar still which uses the principle of evaporation and condensations are able to remove bacterial and chemical pollutants at a low cost (Velmurugan, 2008). In recent years, engineers have conducted experiments on solar stills, to improve its efficiency and the output. Some of the factors of importance were found to be mainly solar radiation, number of sunny hours and the design of the still (Abdallah *et al.*, 2008).

The study has focused on the design, fabrication and characterization of double sloped solar stills, which seek to meet the criteria of sustainability while producing safe and clean drinking water for the local peoples.

Some of the design factors of importance in the study include water depth, surface area, colour of the basin, inclination of the glass, insulation, materials, temperature of the water, air-tightness, wind velocity and temperature differences in the still and ambient air (Velmurugan *et al.*, 2008.)

Some of the useful research work related to this research has been conducted in Baghdad and in Faryab in Afghanistan (Kolstad, 2014). In Baghdad, three solar stills were tested. All had black basins, and two of the stills had additionally jute wicks and in Faryab in Afghanistan three solar still types namely single slope, double chamber, double sloped solar still and wick type solar still were tested and evaluated (Kolstad, 2014).

Mwamburi (2012), in her study of factors affecting access to water supply in Kisauni area, Mombasa County, Kenya, found that water shortage is high in Mombasa County and recommended that evaluation of a cost effective solar still was the solution to the water crisis.

2.2 Theoretical operations of solar stills - evaporation and condensation

The solar distillation systems are classified into two groups; passive and active solar stills, (Fath, 1998). The Principles of operation are the same for all solar stills. The basic principle behind solar distillation replicates the natural process of water purification; evaporation (Badran, 2007). Evaporation of water requires energy. The sun, through direct, diffuse and reflected radiation, supplies this energy to the solar still.

A solar still is an air tight basin that contains saline or contaminated water (i.e. feed water). Usually, the basin of the still is filled with brackish or sea water, the incident solar radiation is transmitted through the transparent cover and is absorbed by a black surface (basin).

From a radiative point of view, the following happens inside the distiller unit: Solar radiation that is not reflected nor absorbed by the cover is transmitted inside the solar still, where it is further reflected and absorbed by the water mass. The amount of solar radiation that is absorbed is a function of the absorptivity and depth of the water. The remaining energy eventually reaches the blackened basin liner, where it is mostly absorbed and converted into thermal energy. Some of this energy might be lost due to poor insulation of the sides and bottom. At this stage, the water heats up, resulting in an increase of the temperature difference between the cover and the water. Heat transfer takes place as radiation, convection and evaporation from the water surface to the inner part of the inclined glass cover. The evaporated water condenses and releases latent heat (Tiwari & Singh, 2004).

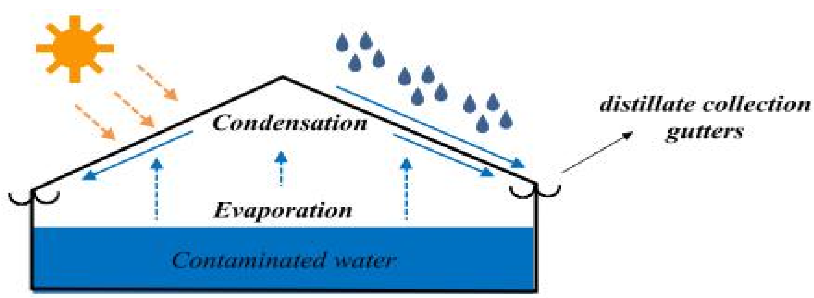


Figure 2.1: Passive solar still; Source: (Murugavel *et al.*, 2008).

To maximize incoming radiation, the inclination of the glass and latitude should be the same. This will give maximum received radiation in a whole year. In the summer period, the declination angle of the sun is at its highest, due to the tilt of the earth on its axis of rotation thereby; having a lower inclination of the glass will increase incoming radiation to the still in the summer period (Al-Hinai *et al.*, 2002).

As the water is heated, the water bonds that are keeping the water molecules together breaks, making it evaporate. The vapour transfers from the basin, towards the cooling glass by convection and evaporation and condenses to water droplets due to adhesion and cohesive forces in glass and water molecules. Since there is a linear relationship between latent heat of evaporation and the surface tension of liquid, evaporation rate increases with increase in latent heat (Armenta-Deu, 1997). The condensed water (i.e. the distillate) trickles down the cover and is collected in an interior trough and then stored in a separate basin (Al-Hayek & Badran, 2004; Tiwari *et al.,* 2003). As the vapour condenses it releases latent heat (Tripathi *et al.,* 2004). The total amount of energy required to change the water into vapour is termed as the latent heat of vaporisation (L) and is calculated as shown in Equation (1) (Arnell, 2002).

$L = 2.501 - 0.0002361T [MJ\ kg^{-1}]$ **…………………………………… Equation *(1)***

As seen in the Equation (1), the energy required is dependent on temperature, in degrees Celsius.

There will be no evaporation if the air is saturated. The vapour pressure deficit (VPD) refers to the amount of moisture in the air, and how much moisture the air can hold when it is saturated. This value increases with temperature, and when exceeded, the dew point is reached. For open water surfaces, the evaporation rate increases with the speed of the wind, thereby leading the saturated air away, and bringing new unsaturated air to the surface. Together, the humidity and turbidity control how the water vapour can diffuse into the surrounding (Arnell, 2002).

For the water vapour to condense into liquid, cooling the air to its dew point, or oversaturating the air with vapour makes it to condense. The glass cover is the condenser in a solar still, and it is therefore important to have a temperature difference between the air inside and outside the still.

The salinity of the water also affects the evaporation rate. As the salinity increase, the evaporation rate decrease, because of the salt occupying space in the water, makes fewer molecules available for evaporation. This is why saline water has a higher saturation vapour pressure than fresh water (Arnell, 2002). Ward *et al.* (2000), however, found this effect to be small, about 2 – 3% lower evaporation rate for saline water over fresh water. Akash *et al.* (2000), found that increasing the salinity percentage by 10 to 75 %, gave a decrease in output by 1.5 litres/day.

It is important that the still is airtight, due to heat loss to the ambient air. The outcome of a still, therefore, depends on both weather conditions and the design of the still. Weather conditions such as solar radiation, temperature and wind velocity are important factors that affect the outcome (Murugavel *et al.,* 2008). Radiation and how it is distributed through the day is the most important parameter to increase the yield of a solar still (Ray *et al.,* 2011).

To estimate the output of a solar still, the following Equation (2) can be used (Twidell and Weir, 2006; Badran and Abu-Khader, 2007):

$$Q = \frac{ExGxA}{L} \qquad \textbf{Equation (2)}$$

Where E = efficiency L = Latent heat, A = area of still, G= daily/annual global horizontal solar radiation (MJ/m^2), and Q is daily output of water from double slope solar still.

Equation (2) above can be used both prior and post experiments, to predict the outcome. A solar still normally has an efficiency ranging between 30 – 60 %, depending on materials and design (Twidell & Weir, 2006; Badran & Abu-Khader, 2007).

2.3 Analysis of Double sloped solar still

This is a basin type solar still with a triangle shaped glass. The glass is attached to the basin and two distillation pipes collect the condensed water, on each side of the rectangular glass to the bucket. The basin is usually made of a good insulator of heat and painted black to avoid heat losses. An absorber plate is usually used which is black in color to absorb all incident radiations to the still.

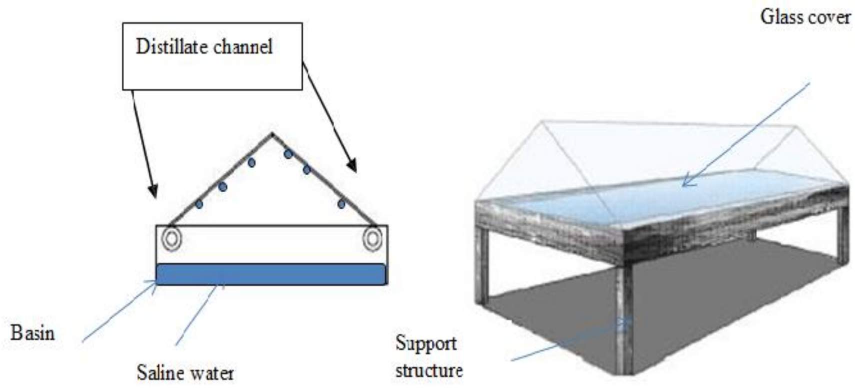


Figure 2.2: Structural design of a double sloped solar still

2.4 Factors affecting double slope solar still designs and fabrication

The productivity of a solar still is affected by ambient conditions (temperature, the insulation, and the velocity of the wind), operating conditions (depth of the water, the orientation of the still and the inlet temperature of the water) and design conditions **(**material selection for the still and cover, slope of the cover, gap distance and the numbers of covers used).

2.4.1 Latitude

Latitude is one of the factors that determine whether single or double slope still should be used. At latitudes higher than 20°, single slope stills with equator facing cover are recommended (Murugavel *et al.,* 2008). For the study area, which is located at a latitude of 4°, double sloped solar still can be successfully used. When the cover is placed with an inclination equal to the latitude angle, it will receive the sun rays close to normal throughout the year (Kabeel & El-Agouz, 2011; Khalifa, 2010). In this way, maximum interception is achieved. However, fundamental in the design is that the distillate condenses on the top cover as a film rather than as droplets. Droplets might otherwise drop back into the feed water and represent a loss of output. To prevent this from happening, the cover should be set at an angle of 10º. This has been observed experimentally by various investigators that the minimum inclination of the glass cover should be at least 10^0, to avoid the drop back of the condensate (Meukam *et al.*, 2004).

2.4.2 Slope of cover and geometry of still angle of inclination

The transparent cover of a solar still should be inclined at an angle (β) to the horizontal plane. It is reported that the optimum value of β is 10^0 which just enables the distillate to flow downwards on the inner surface of the cover without dropping back into the basin (Garg & Mann, 1976). So, β >10^0 is sometimes used depending on the latitude (ϕ) of the site (Nafey, *et al.*, 2000). Generally, β= ϕ -10^0 for summer season (ϕ > 10), β= ϕ for annual performance and β = ϕ +10^0 for winter season (Samee *et al.*, 2007).

Cover inclination of 15^0 is found to be the best. This may be due to several reasons such as the area allocated to condensation is increased which allows better exchange of heat between the cover and the ambient air. In addition, the condensed water drops on the inner surface of the glass to the channel without falling to the basin, because of higher gradient of the glass inner surface (Samee *et al.*, 2007).

2.4.3 Depth of water in still

The performance of a still is considerably affected by the depth of the water in the still. When the level of the water in the still is low, it has a lower thermal capacity and this increases the rate of evaporation and thus higher output. Therefore the lower the water levels the higher the output (Kabeel & ElAgouz, 2011; Tiwari & Tiwari, 2007). When there is low solar energy available in the earlier times of the day, water depth becomes important as you need to heat water quickly to produce fresh water. Solar stills with a water depth of 0.02 m resulted to have the highest annual yield (Kabeel & ElAgouz, 2011; Tiwari &Tiwari, 2007).

2.4.4 Materials for cover

The preferred material for the top cover is glass with a thickness of 3 mm (Kabeel & El-Agouz, 2011). Glass has a higher solar transmittance and a longer lifetime compared to plastic, which is advised to be used for the short-term use only (Murugavel *et al.*, 2008). At the same time, glass is more expensive and fragile. The window glass has hardness of 6.5 in Mohs scale of mineral hardness (Dieter, 1989).

2.5 Design and fabrication processes of double slope solar still

A conventional solar still consists of the following basic components namely basin, support structures, glazing, a distillate trough (channel), and insulation. In addition to these, other components may include sealants, piping and valves, tank for storage**,** an external cover to protect the other components from the weather and a reflector to concentrate sunlight (Gordes, 1985).

Solar still design, the water depth, black dye injection, reduction of the side/bottom heat losses and operational techniques are considered to affect the output of solar stills (Al-ayek & Badran, 2004; Fath, 1998; Tiwari *et al.*, 2003).

In order to build an efficient solar still certain requirements should be met such as to be easily built with locally available materials, light in weight in order to handle and transport easily, should not contaminate the collected fresh water, meet the civil and structural engineering standards and be affordable. The designed solar still should not require any other power source except solar energy and be strong enough to withstand prevailing wind conditions.

A solar still efficiency ranges between 30 – 60 %, depending on materials and design with an effective life span of 10 to 20 years (Twidell & Weir, 2006; Badran & Abu-Khader, 2007).

2.5.1 Distance from the water surface to glass cover

A glass cover that is not more than 5 to 7cm from the water surface will allow the still to operate efficiently. Conversely, as glass-to-water distance increases, heat loss due to convection becomes greater, causing the still's efficiency to drop. Some important stills have been built following the low slope design concept for the glass cover, yet using a short, steeply sloping piece of the glass at the rear (Connor, 1980).

2.5.2 Aspect ratio (R)

Capture of solar energy is also affected by the ratio of the length to width of the still base (R). Effective insolation increased with R but the increase was insignificant for values of R>2.0 for both the double sloped solar still and single sloped solar still at a low latitude (Madhlopa & Clarke, 2011).

2.5.3 Absorbing materials

Various approaches for increasing the basin absorptivity have been tested and found effective in increasing the daily yield of a solar still. These include the use of charcoal (Naim; *et al.,* 2003*)*, black and violet dyes, which were found to be more effective than other dyes (Valsaraj, 2002).

2.5.4 Absorbing Area

The rate of evaporation of water in the solar still (solar still water output) is directly proportional to the surface area of water and efficiency of the still (Velmurugan *et al.,* 2008; Twidell & Weir, 2006; Badran & Abu-Khader, 2007)). The relationship is shown in equation 2. The productivity increases with the increase in the exposure area of the water. The inner surface of the basin is usually blackened to increase the efficiency of the system by absorbing more of the incident solar radiation (Tiwari *et al.,* 2003).

2.5.5 Cooling of cover

Water flow over the still cover at a very low rate has been shown to increase the still output and film cooling parameters such as increasing wind velocity may increase efficiency by 20% (Ayoub & Malaeb, 2012). The convective heat transfer coefficient also increases with wind velocity, leading to a decrease in the cover temperature and hence increases in the overall yield (Sarkar *et al.,* 2008). The productivity of solar still increases with wind speed up to a certain value between 8m/s and 10 m/s for winter and summer conditions, respectively (El-Sebaii, 2007). This value was independent of the still shape and brine heat capacity; the wind was more effective in summer and for higher water masses. Similarly, Fath and Ghazy, (2002), reported that increasing the air flow rate up to 0.5 m^3/s increased productivity to almost double with no further improvement obtained with air flowing beyond this rate. On the other hand, Fath and Hosny, (2002), found that glass cover cooling by wet cloth for 1-, 2-, and 6-hour intervals had no effect on productivity and that continuous cooling is needed to release a significant amount of condensation energy.

2.5.6 Depth of brine

Studies conducted on the effect of water depth in stills have shown that the highest outputs and efficiencies occur at lower depths of 0.02 m (Tiwari & Tiwari, 2007).

2.6 Water quality tests

Sea water which has an average salinity of 35 ppt not only cause bad taste but it also creates stomach problems and laxatives effects (Sukhatme, 1987). The salt contents should not be above the advised mineralogical quantities shown in table 2.1. Solar still not only achieve the desired limit of TDS of 500 ppm but it also removes pathogens, nitrates, iron, chlorides and toxic heavy metals like lead, arsenic, cadmium and mercury completely (Al-Hayek & Badran, 2004; Zein & Al-Dallal, 1984). The process also proved to be effective in the destruction of microbiological organisms present in the feed water (Al –Hayek & Badran, 2004). The distillate is thus high purity water. The advised mineralogical quantities are shown in table 2.1.

Table 2.1: Advised mineralogical quantities (WHO, 2004)

	Total dissolved solids (mg/l)	Bicarbonates ions (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Hardness (mmol/l)	Alkalinity (meq/l)
Minimum	100	30	20	10		
Optimum	250-500		40-80	20-30	2-4	
Maximum						6.5

Storing the distilled water with rain water re- mineralizes th water. If the water seems to be too low on certain minerals, it is possible to re-mineralizes it in an affordable and simple way by dissolution of naturally occurring minerals (Hasson & Bendrihem, 2006; Ruggieri *et al.*, 2008).

2.7 Parameter that can be measured in designed and fabricated solar still

The intensity of solar energy falling on the still is one of the most important parameter affecting production (Ray *et al.*, 2011). The output of a solar still has been measured to be on average 2-5 $l/d/m^2$ (Murugavel *et al.*, 2008; Kabeel & El-Agouz, 2011). The productivity of solar stills is affected by meteorological parameters like solar radiation, sky temperature, wind velocity and ambient temperature (Kabeel & El-Agouz, 2011; Tiwari *et al.*, 2003; Garg & Mann, 1976). Other conditions include geographical location, time of the year, particular solar still design and construction material used, brine depth, water temperature, and other site-specific factors.

2.9 Economic Analysis of the designed and fabricated double sloped solar still

Many factors affect the cost of distillate obtained from a solar desalination unit. Both capital and running costs are influenced by unit size, site location, feed water properties, product water quality, qualified staff availability, etc. The main economic advantage of solar desalination is that it does not require much infrastructure, and it is simple to locally design, install, operate and maintain. The better economic return on the investment depends on the production cost of the distilled water and its applicability (Fath *et al*., 2003; Kumar & Tiwari 2004; Govind & Tiwari,1984).

The life cycle cost analysis should be done in order to make economic viability comparison with other designed and fabricated double solar stills for economic analysis (Kudish *et al.*, 1986; Tiwari, 2011; Garg & Prakash, 2000; Solanki *et al.*, 2009).

The CRF (capital recovery factor), the FAC (fixed annual cost), the SFF (sinking fund factor), the ASV (annual salvage value), average annual productivity (M) and AC (annual cost) are the main calculation parameters used in the cost analysis of the desalination unit.

The AMC of the solar still required are regular filling of brackish water, collecting the distilled water, cleaning of the glass cover and removal of salt deposited (scaling). As the system life passes on, the maintenance on it also increases. Finally, the CPL (cost of distilled water per litre) can be calculated by dividing the annual cost of the system (AC) by annual yield of solar still (M).

The above-mentioned calculation parameters can be expressed as follows:

Capital Recovery Factor (CRF):

$$CRF = \frac{i(1+i)^{n}}{(1+i)^{n}-1)}$$ ……………………………………………**Equation *(3)***

Where i= interest rate, n = number of useful years

Hence the first annual cost (FAC)

$$FAC = CRFXP$$ ……………………………………………………**Equation *(4)***

Annual Salvage Value:

The sinking fund factor (SFF) for a system is given by:

$$SFF = \frac{i}{(1+i)^{n} - 1)}$$ ………………………………………………… **Equation *(5)***

Therefore, if the salvage value of the system is S then, Annual salvage value(ASV)

$$ASV = (SFF)XS$$ ……………………..…………………………**Equation *(6)***

S =0.2 P (assuming 20% of present value as salvage value; no reuse of salvage materials)

Further, the system requires some maintenance and it is a varying quantity, therefore the annual maintenance cost should also be considered.

$$AMC = 0.15FAC$$ ………………………………………….…………**Equation *(7)***

(Assuming 15% cost of fixed annual cost

Annual Cost/m = (First annual cost + annual maintenance cost –annual salvage value)

Annual yield = daily output yield (l) x365 days

Annual cost/L (CPL) = [Annual first cost/ Annual yield]

Assuming the reuse of various components even after the useful life of the system is over; the salvage value can be estimated to be 35% of the initial cost, useful life 10 years, interest rate 12% and maintenance cost as 15% of the annual first cost. Where P is the present capital cost of desalination system; i is the interest per year, which is assumed as 12%; n is the number of life years, which is assumed as 10 years in most analysis. Solar stills represent a low-cost technology with low-cost maintenance, which can be carried out by unskilled manpower (Tiwari *et al.,* 2003).

2.10 Economic viability analysis

The factors that influence the systems economic viability are the outputs and costs of the solar still systems, the cost of alternative energy source, cost of operation and maintenance, and the geographic location of the system, i.e. solar intensity, environmental temperature and humidity.

The net present value method used for cost analysis is a comparison between the investments made at present using the present value of money considering interest rate over a period of time. The net present value analysis was made according to Equation (8) below (Wolpert, 2003)

$$NPV = I_O + \sum_{j=1}^{t} \frac{F_t}{(1+i^t)} \quad \textbf{Equation}\textbf{\textit{(8)}}$$

Where: *I*= capital cost, *F*= running cost, *i*= interest rate, *t*= time in years

The net present value (NPV), usually shows the sum of the present worth of the cash flows within the considered analysis period, results > 0 validates the project as being economically feasible.

The Savings-to-Investment (SIR); evaluates the ratio of the savings to investment, where result = 1 shows that the initial cost is totally recovered, results > 1 shows that the savings will be more than investments and results < 1 shows that the cost would be greater than savings over the analysis period.

The Internal rate of return (IRR) is the discount rate that makes the net present value of the initial investment equal to zero.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study design

The study was conducted to determine if the solar energy potential available in Kilifi County can be used for desalination processes at household levels using locally available materials and the variation of other parameters (water salinity, ambient temperature, humidity and season variation). It was based on quantitative data where the relationship between various parameters was determined. The study uses correlation and linear regression to determine relations between various variables that affect desalination process.

3.2 Study area

The study was carried out in Kilifi County with a targeted population of people living in Kilifi County. Kilifi County is one of the 47 counties in the Republic of Kenya. The County lies between latitude 2° 20’ and 4° 0’ South of the Equator and between longitude 39° 05’ and 40° 14’ East of the Greenwich Meridian, (SOK, 2012). The County is located in Kenya’s Coastal region and borders Kwale County to the south west, Taita Taveta County to the west, Tana River County to the north, Mombasa County to the south and the Indian Ocean to the east. It covers an area of 12,609.7 km^2. Kilifi has the cold season from March to June and hot season between November and February. Kilifi town is the County headquarters and data was collected at Mtwapa agro-metrological station. The location of Kilifi County within the republic of Kenya is shown in Figure 3.1 (SOK, 2012).

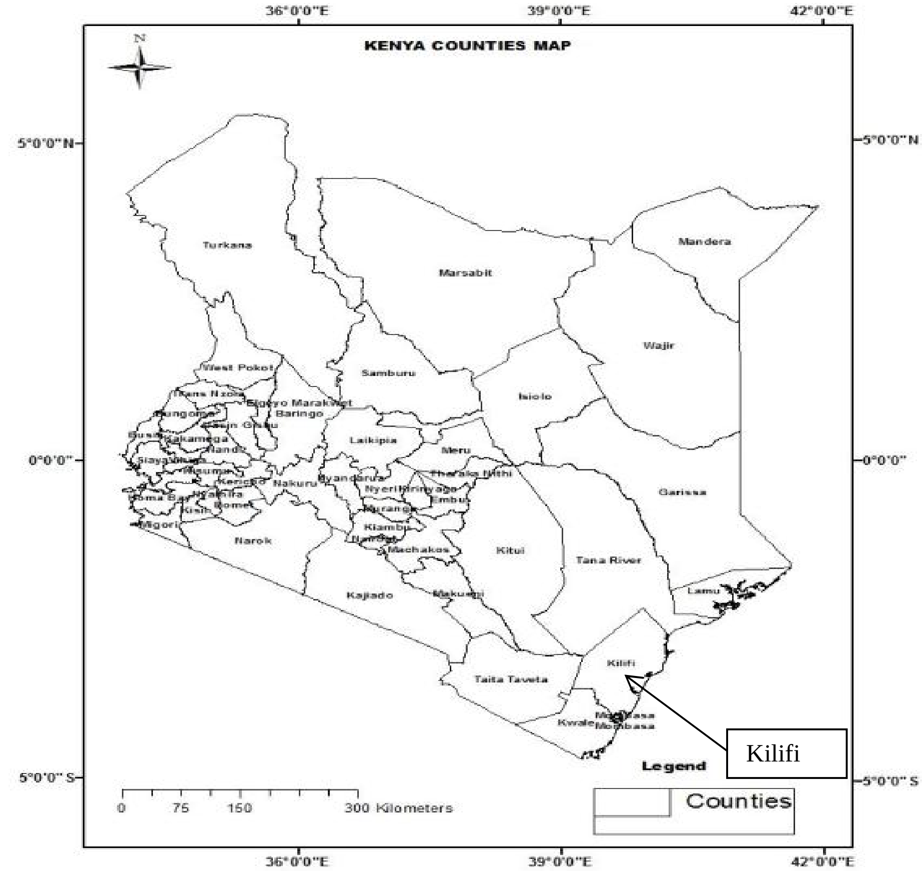


Figure 3.1: Location of Kilifi in Kenya, Source Survey of Kenya maps 2012.

The annual temperature ranges between 21°C and 30°C in the coastal belt and between 30°C and 34°C in the hinterland. The average annual temperature is 26 °C. The county experiences relatively low wind speeds ranging between 4.8 km/hr and 12 Km/hr. The highest evaporation rate is experienced during the months of January to March (dry season) in all parts of the County (Kilifi, 2013; Kenya meteorological department, 2018).

3.3 Design and fabrication of double slope solar still

The design factors considered were slope of cover and geometry of the still, angle of inclination (β), depth of water in the still, materials for cover, vapour leakage and insulation, distance from the water surface to glass cover, aspect ratio(R), absorbing materials, absorbing area, material for basin and collection channel.

The designed and fabricated double slope solar still consists of a basin made of block board which is painted black with an absorbing plate made of a damp proof polythene paper, black in colour that is used in the construction of houses foundation. The double slope solar stills basin was wooden box with dimensions of 1.5 m long and 0.79 m width and height of 150 mm. The total height of the still was 244 mm, including the glass cover. The distance of glass cover from water surface was set as 9.4 cm with Aspect ratio (R) greater than 2. To minimize vapour leakage a sealant (silicon) was applied at the various joints on the basin which is made of block board which is a good insulator. The bottom and sides of the basin were polished and painted black. The block board also consists of channels attached to it and a tap drain the concentrated brine after desalination.

The cover material was glass of 4 mm thickness which has a Mohs hardness of 6.5. This was hard enough to avoid breakage when lifting the glass cover. The cover was inclined at an angle of inclination 15^0. This catered for latitude, giving maximum solar radiation absorption, avoiding the droplets to fall back and allows easier cleaning of the sloped surface. Water depth used was 0.02 m for easier evaporation.

The condensed water was collected with the help of a plastic channel which is installed underneath the lower side of the glass. It collects the fresh water into the channel and is connected to an external storage bottle with a plastic pipe/hose pipe. Detailed technical drawings on designed and fabricated double slope solar still are found in Appendix 18.

3.4 Measurements

3.4.1 Research instruments

The experiment was conducted using the following research instruments: thermometer graduated flask, stop watch and a clock.

Gunn- Bellani Radiation Integrator

The pyranometer is a type of actinometer that can measure solar irradiance in the desired location. Figure 5 shows Gunn- Bellani radiation integrator used in the study.

Figure 3.2: Pyranometer

3.4.2 Measuring equipment accuracies

Table 3.1 presents the accuracies and errors for the instruments used. The maximum possible error occurred in any instrument is equal to the ratio between its least count and minimum value (within the range given).

Table 3.1: Accuracies of the instruments

Instrument	Accuracy	Range	% Error
Thermometer	$\pm$ 1^{o}C	0-100 ^{o}C	0.5
Measuring jar(1000ml)	$\pm$ 10ml	0-1000ml	10
Measuring jar(100ml)	$\pm$ 1ml	0-100ml	10
Gunn-Bellani radiation integrator(MJ/m^2/day	$\pm$ 20 W/m^2	0-25000W/m^2	0.5

3.4.3 Parameter Measured

The parameters that were measured and recorded in order to characterize the double sloped solar still were, the intensity of solar energy, the water output of a solar still, solar radiation, wind velocity, ambient temperature and time of the year.

3.5 Method

3.5.1 Experiment set up

The experiment was conducted during the month of September and October 2016; with data collection done during the day. The solar still was facing North-South direction and was filled with salty water up to a level of 20 mm.

Hourly measurements of radiation, water output, relative humidity, weather, rainfall, and dry bulb temperatures were recorded between 08:00 am and 4:00 pm (at an interval of one hour) and between 4:00 pm to 8.00 am cumulative water outputs was measured in total at 08:00 am and recorded.

3.5.2 Water quality testing

To ensure water quality in terms of cleanness the double slope still was rinsed with collected distilled water. Water analysis was conducted on different days in the Mombasa government chemistry laboratory using different samples. Physical and chemical parameters recorded were appearance, colour, odour, pH, total alkalinity, total hardness, chloride content, electrical conductivity (EC), salinity, free carbon dioxide, phosphate, fluorides, oxygen absorbed, bicarbonates, non carbonates hardness, carbonate hardness, heavy metals (copper), iron, sodium, potassium, calcium, magnesium and total dissolved solids (TDS).

The pH was measured by first calibrating the pH digital meter scale using the standard procedure, then water was put in a beaker, electrodes inserted (care was taken to avoid contamination by use of distilled water to clean electrodes) and pH measured.

Chemical properties were analyzed by putting test water in the beaker, adding the required test reagent and following the standard procedures for each chemical properties like total alkalinity, total hardness, chloride content, electrical conductivity (EC), salinity, free carbon dioxide, phosphate, fluorides, oxygen absorbed, bicarbonates, non carbonates hardness, carbonate hardness, heavy metals (copper), iron, sodium, potassium, calcium, magnesium, and total dissolved solids (TDS). The instruments were calibrated before the test. The results obtained were tabulated in results tables, chemical report generated and analyzes carried out according to Kenya standards procedure (KS 05-459 part 1:1996). Appearance, colour and odour are recorded pre and post distillation by physical examination of the samples.

In bacterial test, water samples were collected in sterile bottles and taken to government chemist for analysis. The water was then tested according to Kenya standards (KS 05-459 part 1:1996) procedure for testing (kept for 48 hours).

Bacteriological contaminants parameters such as Escherichia coli (before distillation) and product water (after distillation by a solar still) were analyzed using Kenya standards (KS 05-459 part 1:1996) and recorded. A report on the level of water contamination before and after distillation was developed.

3.6 Data processing and analysis

Microsoft excel as statistical tools and software was used to analyze statistically the data collected i.e linear regression and correlation was used which gave various properties of double slope solar still. For example, a linear regression model was developed to estimate expected output (response) when solar irradiation increased in the double slope solar stills. The data obtained was plotted in a graph, where solar still water output was the dependent on the y axis and the solar irradiation was the independent in x axis. Using the linear regression function on Microsoft excel, correlation factor and linear regression equation was obtained. The correlation factor and linear regression equation obtained were used to characterize the double solar still by getting solar still water output using data obtained from the metrological departments.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results

The data was gathered from 19.09.2016 to 9.10.2016 under the local weather conditions of Kilifi County (35.12° N latitude and 33.95° E longitude). Parameters that were measured are dry bulb temperature (˚C), solar radiation (W/m^2) solar still Output (ml), registrations on wind and weather conditions which are in Table 4.1 for an extract of typical data collected on 21st, Sept 2016.

Table 4.1: Typical data collected on 21st, Sept 2016

Time	dry bulb temp	wind velocity	relative humidity	weather -sky	Rainfal (mm)	solar irradiation (MJ/m^2)	still output (ml)	Cumulative solar still outputs
8.00	26.3	4	66	sunny	0	8.94	318.75	318.75
9.00	27.5	8	60	sunny	0	8.86	0	318.75
10.00	28	6	59	sunny	0	11.43	15	333.75
11.00	28	8	60	sunny	0	12.02	53.75	387.5
12.00	28.6	3	59	sunny	0	11.21	123.75	511.25
13.00	28.7	6	56	sunny	0	12.5	220	731.25
14.00	29	10	55	sunny	0	11.9	216.25	947.5
15.00	27.8	6	62	sunny	0	10.59	187.5	1135
16.00	27.8	6	62	sunny	0	9.59	131.25	1266.25

Table 4.1 presents data collected on 21st, September 2016 between 8 am to 4 pm. The cumulative solar still output were worked out and increased from 318 ml at 8 am to 1266 ml at 4 pm. The whole day was sunny. Data on dry bulb temperature, wind velocity, relative humidity, weather, rainfall, solar irradiation and double slope solar still output between 19th September, 2016 to 9th October, 2016 are found in Appendix 20.

4.2 Water output (Yield) from the double slope solar still

The daily output of a solar still depended on weather conditions and the amount of solar energy available. The fabricated double solar still was able to produce 1.652 litres per day per square meter during the period which data was collected (September and October 2016). The solar still output obtained agrees very well with research work carried by Hamed *et al*., 1993, who found out that the daily yield usually never exceeds 4-5 liters/m^2/day due to the heat losses. An extract of the data on 21st September 2016 is shown in Table 4.1.

4.3 Graphical representations showing various relationships-characteristics of double slope solar still

Figure 4.1, Figure 4.2, Figure 4.3 and Figure, 4.4 presents the various characteristics of the designed and fabricate double slope solar still.

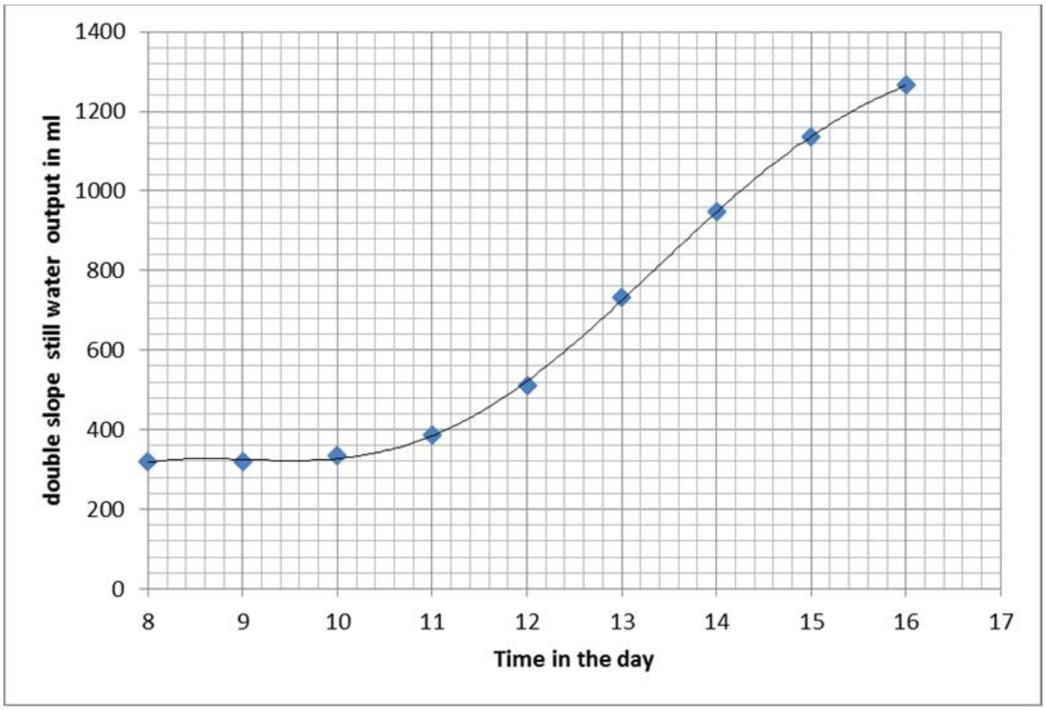


Figure 4.1: Cumulative Solar still output against time of the day (21st Sept 2016)

Figure 4.1 presents cumulative water output in ml against time in day from 8 am to 4 pm. The graph in Figure 4.1 shows that the volume increased from 318 ml at 8 am to 1266 ml at 4 pm. The results for double solar still water output in millimeters against time of the day from 19th September, 2016 to 9th October, 2016 are found in Appendix 20

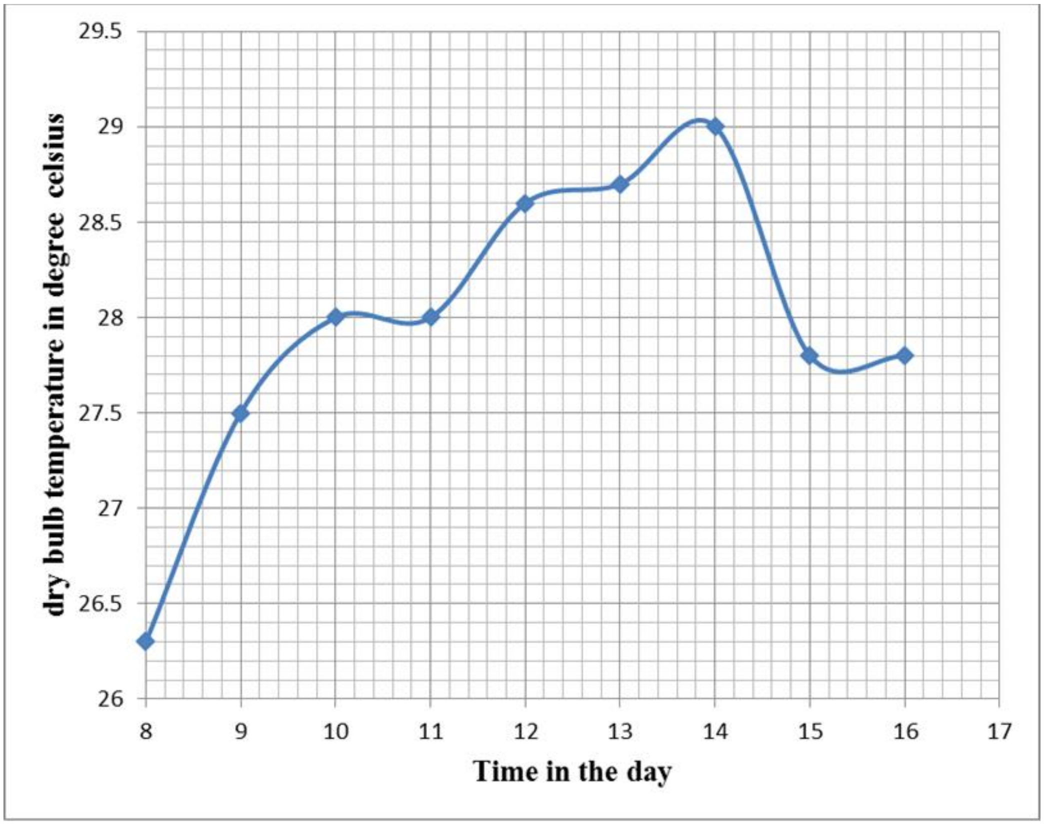


Figure 4.2: Dry bulb temperature against time of the day (21st, Sept 2016)

The whole day was sunny and from graph in Figure 4.2 above, it is evident that the dry bulb temperature increases from 8 am to 2 pm and starts decreasing. As the temperature increased, the output of the double slope solar still increased and at 2 pm the production continued to increase due to the heat absorbed by the water until 4 pm. The graphs for dry bulb temperature against time of the day from 19th September, 2016 to 9th October, 2016 are found in Appendix 20

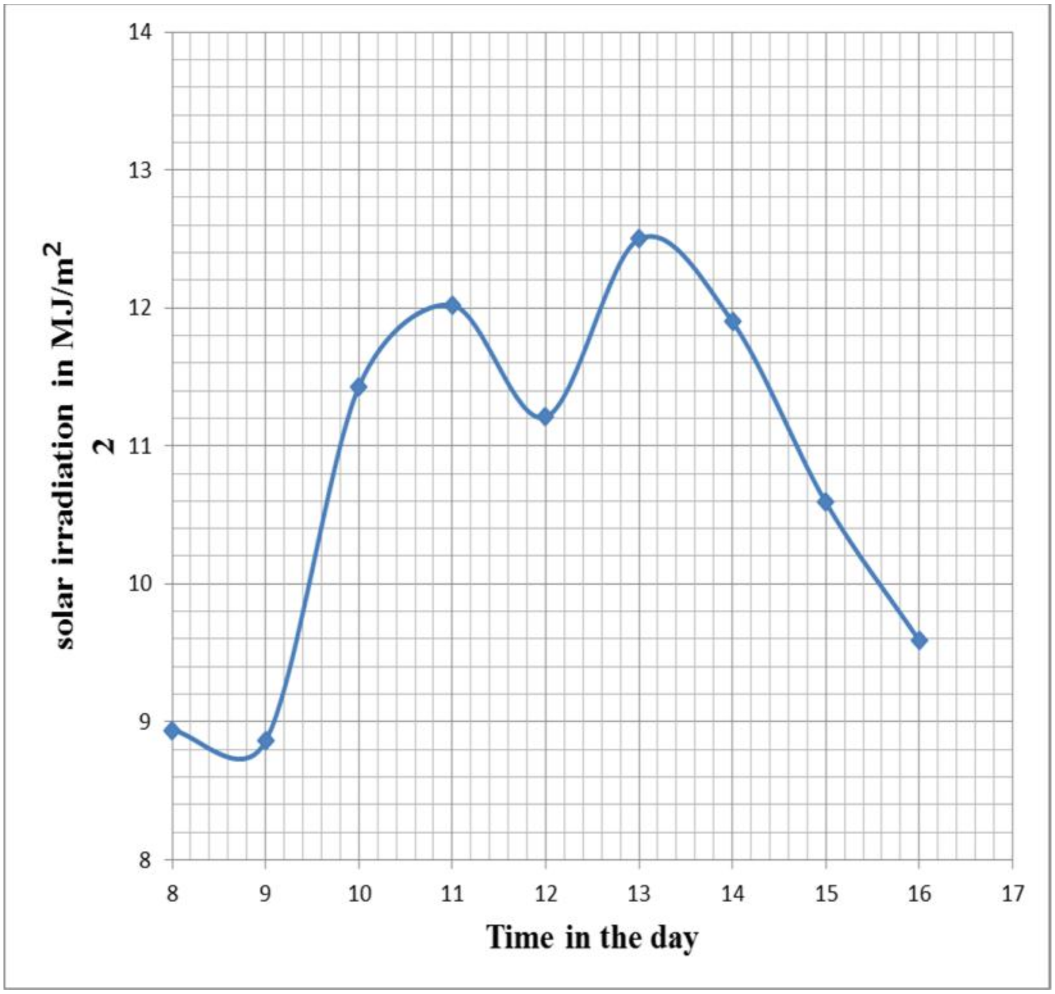


Figure 4.3: Solar irradiation against time of the day (21st Sept 2016)

The whole day was sunny and from the results, it is evident that a graph exhibits the same type of curve for all the days with an increase from 8 am to maximum solar irradiation at the 1 pm and decrease of irradiation from midday to 4 pm. The results for solar irradiation in MJ/m^2 against time of the day from 19th September, 2016 to 9th October, 2016 are found in Appendix 20

4.4 Correlation and regression analysis

Figure, 4.3 and Figure, 4.4 presents correlation and regression analysis

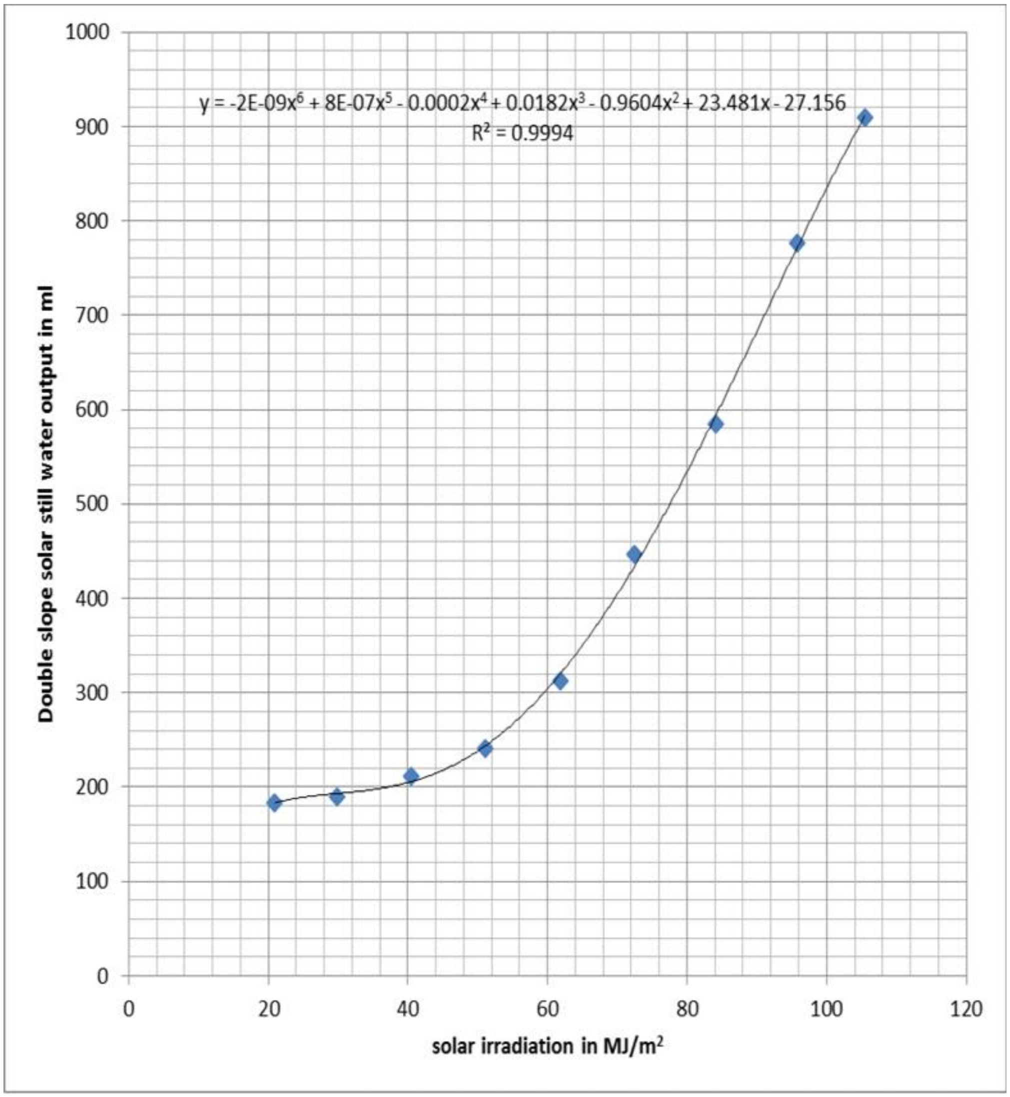


Figure 4.4: Double slope Solar still output against solar irradiation (19th Sept 2016)

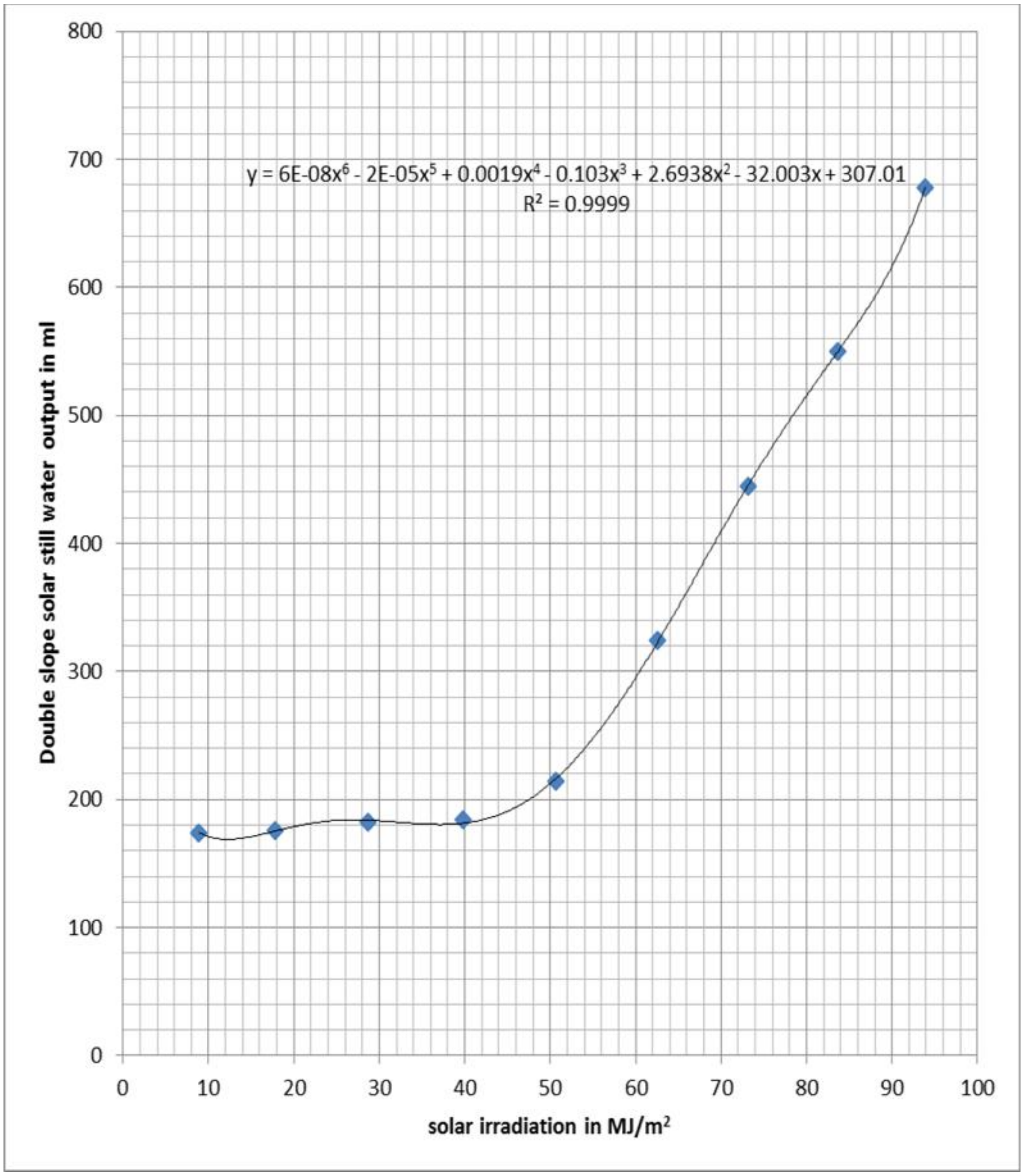


Figure 4.5: Solar still output against solar irradiation (27th Sept 2016)

From the two sample graphs in Figure 4.4 and 4.5, it is evident that there is a strong correlation between the solar still output and solar irradiation Rsq (%) of 99.94 and 99.99. The results for double slope solar still water output in millimeters against solar irradiation in MJ/m^2 from 19th September, 2016 to 9th October, 2016 are found in Appendix 20. Table 4.2 presents the summary of correlation factor (Rsq (%).

Table 4.2: Correlation between water output and solar irradiation

Date	Water output in millilitres (Q)	Efficiency (E) %	Correlation Rsq (%)	Weather
19th September	1072	13.51	99.94	Cloudy and sunny
20th September	726	9.15	99.96	Cloudy and sunny
21st September	1266	15.95	94.58	Whole day sunny
22nd September	771	9.72	99.82	Cloudy and sunny
23rd September	1652	20.82	89.98	Whole day sunny
24th September	958	12.07	86.38	Cloudy and sunny
25th September	998	12.58	96.53	Cloudy and sunny
26th September	635	8.00	99.82	Cloudy and sunny
27th September	504	6.35	99.99	Cloudy and sunny
28th September	1003	12.64	99.99	Whole day sunny
29th September	1008	12.70	99.51	Cloudy and sunny
30th September	212	2.67	99.01	Cloudy and sunny
1st October	884	11.14	97.47	Cloudy and sunny
2nd October	805	10.14	98.34	Cloudy and sunny
3rd October	7725	97.34	99.93	Rainy and sunny
4th October	938	11.82	99.93	Cloudy and sunny
5th October	517	6.51	99.89	Cloudy and sunny
6th October	948	11.95	99.54	Cloudy and sunny
7th October	210	2.65	99.03	Cloudy and sunny
8th October	588	7.41	96.21	Cloudy and sunny
9th October	228	2.87	96.5	Whole day rainy

From the Table 4.2 it is evident that there is a strong correlation between solar still output and solar irradiation and the Equation $y = 0.103x^3 + 2.6938x^2 - 32.003x + 307.05$ *(valid during the day and y represent solar still output in milliliters and x represent the solar irradiation in MJ/m^2)* where Rsq is 99.9% can be used to approximate solar still output where solar radiation is known.

An increase in correlation is found when excluding rainy days, 23rd and 24th September 2016 and 3rd October 2016 with a value of R square greater than 90%. An increase in solar still output in rainy periods was due to water droplets entering the collection channel; contributing to a lower correlation with solar irradiation. Solar still water output and solar irradiation are correlated and can be noted that that evaporation rate increases with an increase in the amount of solar energy available. Cloud cover affected the availability of solar irradiation by absorbing and diffusing some radiations thus to greater extent affected the output and correlations.

4.5 Efficiency

The efficiency was calculated for a sample day taking the annual global horizontal radiation set to be 5.5 kWh/m^2/day (19.8 MJ/m^2/day), approximate area 1 m^2 and latent heat of evaporation is 2.494MJ/kg. The total amount of energy required to change the water into vapour, latent heat of vaporisation (L) is calculated using Equation (1)

Where for sample day 21st September 2016 mean temperature is 27.97^{o}C and thus latent heat of vaporisation is 2.494MJ/kg.

Equation (2) gives the efficiency calculated as shown for a sample day 21st September 2016.

$Q = \frac{ExGxA}{L}$**..Equation *(2)***

E = efficiency, L = Latent heat, A = area of still, G= daily/annual global horizontal solar radiation (MJ/m^2), and Q is daily output.

L=2.494MJ/kg *A = 1.185m^2 G=19.8MJ/m^2/day thus efficiency is*

E=15.95%

Using the above-worked example; the value for efficiencies of double sloped solar still were worked out and shown in Table 4.3.

Table 4.3: Mean dry bulb temperature, water output, efficiency and weather

Date 2016	Mean dry bulb temperature	Water output in millilitres (Q)	Efficiency (E) %	Weather
19th September	27.56	1072	15.83	Cloudy and sunny
20th September	26.78	726	9.15	Cloudy and sunny
21st September	27.97	1266	15.96	Whole day sunny
22nd September	27.71	771	9.72	Cloudy and sunny
23rd September	27.44	1652	20.82	Whole day sunny
24th September	27.9	958	12.07	Cloudy and sunny
25th September	27.83	998	12.58	Cloudy and sunny
26th September	27.9	635	12.78	Cloudy and sunny
27th September	28.07	504	8.54	Cloudy and sunny
28th September	26.08	1003	12.64	Whole day sunny
29th September	27.8	1008	13.71	Cloudy and sunny
30th September	27.74	212	2.67	Cloudy and sunny
1st October	28.28	884	11.14	Cloudy and sunny
2nd October	27.7	805	10.14	Cloudy and sunny
3rd October	28.07	7725	9.73	Rainy and sunny
4th October	28.7	938	11.82	Cloudy and sunny
5th October	28.46	517	6.51	Cloudy and sunny
6th October	28.47	948	11.95	Cloudy and sunny
7th October	28.24	210	2.65	Cloudy and sunny
8th October	28.96	588	7.41	Cloudy and sunny
9th October	27.98	228	2.87	Whole day rainy

From the experiment, the double sloped solar still has an efficiency that ranges between 12 % and 20 % for a whole day sunny and below 12% if cloudy. On the 19th September 2016 the weather was cloudy and rainy with occasional sun gaps, and is, therefore, in reality, receiving reduced amount of radiation. Clouds also reduce the amount of solar irradiation reaching the solar still. On 9th October the whole day was rainy. It is also evident that at an average temperature of 28^{o}C and the whole day is sunny the double slope solar still has high efficiency and high production with the highest production on 23rd September 2016. On 3rd October the production is high due to the presence of rain water that trickled to a collection point.

From table 4.3 on mean dry bulb temperature, water output, efficiency and weather it was found out that the efficiency of double slope solar still agrees very well with the work done in New Delhi climate by Dwivedi & Tiwari, 2008, on double slope solar still which had an efficiency of 25% to 34%. Badran *et al.*, (2013) found out the highest temperature developed inside the distilling device was 51°C at ambient temperature of 24°C, with daily water production of 1.2 liters/m^2/day, and the efficiency of the solar still was 15%.

Samee, *et al.*, (2007) reported that the efficiency and daily productivity of the simple basin-type solar still under study are 30% and 3.1 litres/m^2/day. The double slope solar stills have low efficiencies as this is well reported by Malik *et al.*, (1982), who analyzed the reason for lower energy efficiency of solar stills. It was found that the radiation loss from the saline water surface to the cover was the largest heat loss of 26% of the incident solar radiation, heat loss resulting from reflection (11%) and absorption (5%) of solar radiation by the glass cover. The ground and edge losses were only 2% with re-evaporation of distillate and other unaccounted losses found to be 17% (Malik *et al.,* 1982).

Considering mean efficiency of 16%, annual average temperature 26 °C, solar irradiation 19.8 $MJ/m^2/day$ (5.5 $kWh/m^2/day$), L=2.494MJ/kg, A = $1.185m^{2,}$, G=19.8$MJ/m^2/day$ for Kilifi County (Kenya meteorological department, 2018) and using Equation (1) and (2) the output of double slope solar still is calculated as follows:

$$Q = \frac{ExGxA}{L}$$ ……………………………………………………….... ***Equation.(2)***

$$Q = \frac{0.16x19.8x1.185}{2.494}$$

Q =1.51 liters

Using correlation equation with R sq as 99.9% $y = 0.103x^3 + 2.6938x^2 - 32.003x + 307.05$, the output from the double slope still is calculated as 1.52 liters.

From the above calculations, it is evident that the approximate mean water output of double slope solar still is around 1.5 liters.

4.6 Cost estimations

When choosing materials for the solar stills, the availability and price were considered. Block board, silicon glue, PVC pipes, garden hose, paint, wood, polythene and glass were all easy to obtain in Kilifi County. An overview of material cost and the total cost for the double slope solar still is presented in Table 4.4.

Table 4.4: Material cost estimates

Sno:	Material	KSHs	USD$
1	Block board	3000	29.13
2	Labor costs-carpenter	2000	19.42
3	Damp proof Polythene paper (100mm width,3m length and 0.7mm thickness)	500	4.85
4	Ordinary Glass 4mm thickness	3000	29.13
5	Paint 2 litres	500	4.85
6	Collecting jar	100	0.97
7	Glue and silicon	150	1.46
8	Plastic, distillation channel/garden hose	80	0.78
Total		**9350**	**90.78**

1USD =Ksh 103(as at 19th, January 2017 Central Bank of Kenya)

For cost effective analysis as shown in Table 4.4, no consideration was made for certain costs such as packaging and transport cost to the site. Other costs such as that of raw water and concentrated salt disposal are not included.

The total fabrication cost is 90.78 USD and the cost could be lower when produced in large quantities for commercial purpose.

4.7 Economic analysis

The double slope solar still water output analysis was based on the data obtained from the chemical, physical and bacterial analysis which shows that the water is within the Kenya standards (KS 05-459 part 1:1996). Table 4.5 presents water quality parameters of water pre and post distillation process.

For the designed double sloped solar still, economic analysis was carried out using Equations (3), (4), (5), (6), (7) and (8) and calculated values are presented in Table 4.5 and Table 4.6.

Table 4.5: Costs parameters

S.No	Parameter	Value
1	CRF	0.177
2	SFF	0.057
3	P (Kshs)	9350
4	S (Kshs)	3272.5
5	FAC (Kshs)	1654.95
6	ASV (Kshs)	186.53
7	AMC (Kshs)	248.24
8	M(annual yield) (L)	351
9	Cost/L (Kshs)	**4.89**

LCC analysis for the fabricated double slope solar still

Life Cycle Cost analysis (LCC) for modified solar still is given as:

Estimated annual clean water output = average daily output x 365 day

= 0.96158litres/day x 365days

= 351 litres

The annual savings = annual output x water price (Kshs 50/ litre), which is = Kshs 17548.84

- Total annual savings = Kshs 17548.84
- The initial investment = Kshs 9350
- analysis period =10 years
- Discount rate = 4%

Table 4.6 presents the result of the LCC analysis for the fabricated double slope solar still.

Table 4.6: LCC analysis for the fabricated double slope solar still

Economic evaluation	Results
Net Present Value (NPV) in Kshs	132,987
Savings to Investment Ratio(SIR)	15
Pay back	0.5
Internal Rate of Return (IRR)	249.20%

From Table 4.6 above it is evident that: NPV was Kshs 132,987 which is greater than zero hence the project is valid and economically feasible, Savings-to-Investment (SIR) is equal to 15 which are greater than one hence the savings will be more than investment cost and payback period of still is 0.5 years which are 195 days to recover initial investment cost.

4.8 Payback Period

Daily distilled water production per unit area (mean for September to October) = 0.962 L/m^2/day

Cost of distilled water in Kenyan market = kshs 50/L

Saving on distilled water produced everyday (gain) = 0.962 x 50 = Kshs 48.1/ day

Initial cost of present still = Kshs 9350/ m^2

So pay-back period of still is = 195days.

4.9 Comparison with other designed solar still world wide

The designed double slope solar still under Kenyan climatic condition (Kilifi County) with average daylight hours of 6.9 hours (2525 hours of sunlight per year) had an area of 1m^2, annual yield in litres (M) 0.962L, investment cost (P) Kshs 9,350 (USD$ 90.8) and cost per litre (CPL) of Kshs 4.89 (0.05 USD$).

It is evident that cost per litres agrees very well with other designed solar stills with approximate area of 1m^2 (Samee *et al.*,2007, Pakistan climate, CPL 0.063 USD$; Abdel-Rehim &Lasheen, 2007, Egypt , CPL 0.058 USD$; Velmurugan *et al.*, 2008, India, CPL 0.054 USD$; Sadineni *et al.*, 2008,USA, CPL 0.054 USD$; Elsebaii *et al.*, 2008, Egypt, CPL 0.052 USD$; El-Bahi &inan, 1999, Turkey, CPL 0.06 USD$). See Appendix 16 for more detailed comparisons by Kabeel & El-Agouz, 2011.

4.10 Water quality

The values of EC < 375 ($\mu\Omega/cm^3$) were measured in the distilled water which is found to be within the Kenya standard ranges (KS 05-459 part 1:1996). The still was successful in removing pathogenic bacteria by more than 80%. Coliform were some of the bacteria that were not completely eliminated. This is shown in the government chemist report on bacterial analysis found in Appendix 10,13 and 14 on government chemist lab results on processed water bacteria analysis. These obtained parameters of the product water were then compared with Kenya drinking water standards (KS 05-459 part 1:1996) and World Health Organization standards (WHO, 2004) and found that most of the values obtained were within the acceptable ranges provided by the Kenya and WHO, 2004 standards.The summarized comparison is found in Table 4.7 on parameters on water quality of borehole and distilled water samples pre and post distillation process.

The distilled water was run through the free air to allow re-mineralization as shown in Figure 4.6.

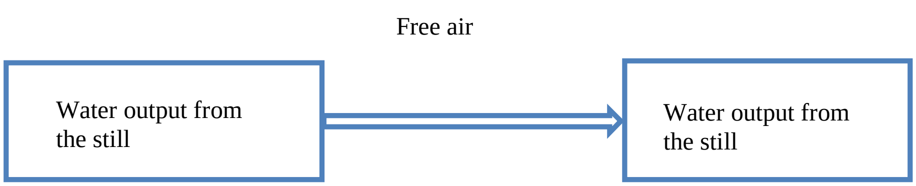


Figure 4.6: Schematic diagram showing re-mineralization

This had a detrimental effect as it may have come into contact with coliform bacteria present in the air through the dust. In order to make the water safe and clean for drinking, chlorination is advised as an option.

Controlled use of lime, chlorine, carbon dioxide or air bubbling has been proposed and practiced by various researchers for portable drinking water (Khawaji, *et al.*, 1994; Kirby, 1987; World Health Organization, 1979; Liberman & Liberman, 1999; Gabbrielli, 1981; Ludwig *et al.*, 1986; Yamauchi, *et al.*, 1987; AlRqobal &Al-Munayyis, 1989; *Kutty et al.*,1991).

Chlorine is easily available at no cost from the Kenyan ministry of health at public health office all over the County. Chemically the water is found to conform to the standard set by KEBS and WHO on water quality.

Table 4.7 presents a typical summary report of government chemist showing borehole water and solar still water output quality in terms of bacteria and chemical properties.

Table 4.7: Water quality parameters of borehole and distilled water samples

Parameter Date sample collected (values measured in PPM mg/L)	Distilled water sample 1 26/10/2016	Distilled water Sample 2 31/10/2016	Borehole sample 3 31/10/2016	Kenya Standards (KS 05-459 part 1 1996) (maximum limits ppm)	Remarks
Appearance	Clear	Clear	Clear	-	Within limits
Color (hazen units)	10	16	10	25	Within limits
Deposits	NIL	NIL	NIL	-	Within limits
Odour	unobjectable	Unobjectable	unobjectable	-	Within limits
Turbidity (NTU)	3.77	16.2	0.54	5	Within limits
Electrical conductivity at 25^{o}C (μohms/cm^{3})	52.9	375	972	2500	Within limits
Free carbon dioxide	38	1	50	-	Within limits
Phosphate PO^{-3}_{4}	0.96	0.1	0.41	2.2	Within limits
oxygen absorbed ,four hours 27^{o}C (O)	0.8	0.8	0.8	1	Within limits
Alkalinity as $CaCO_3$ Phenolphthalein (carbonate)	NIL	NIL	NIL	-	Within limits
Methyl Orange (Bicarbonate)	44	16	380	300	Within limits
Chloride ($Cl^{-)}$	20	8	84	250	Within limits
Nitrates(/NO^{-2-}N)	0.07	0.4	0.5	35	Within limits

Sodium(Na)	10	2	69	200	Within limits
Potassium(K)	1	2	3	100	Within limits
Calcium(Ca)	1.54	1.7	0.38	150	Within limits
Magnesium(Mg)	1.25	1.9	2.31	100	Within limits
Total Dissolved Solids, residues dries at 180^oC	36	26	660	1000	Within limits
PH	6.28	6.7	6.9	6.5-8.5	Within limits
Total Coliform Count (MPN/100ml)	>2400	>2400	>2400	NIL	Above limits Chlorination to be done
Faecal Coliform (E.coli) Count (MPN/100ml)	91	3	16	NIL	Above limits Chlorination to be done

From Table 4.7 on parameters of borehole and distilled water samples pre and post distillation process, it is observed that the samples of the distilled water collected on, 6th October,2016 and 31st October, 2016 are conforming to maximum limits parts per million on Kenya standards (KS 05-459 part 1 1996) and World health organization standards, 2004 on advised mineralogical standards.

Physical and chemical parameters for the distilled water samples were tested and recorded like appearance, colour in hazen units, odour, pH, total alkalinity, total hardness, chloride content, electrical conductivity (EC), salinity, free carbon dioxide, phosphate, fluorides, oxygen absorbed, non carbonates hardness, carbonate hardness, heavy metals (copper), iron, sodium, potassium, calcium, magnesium and total dissolved solids (TDS) were found to be within the Kenya standards maximum limits (KS 05-459 part 1 1996).

From Table 4.7 on water quality parameters of borehole and distilled water samples pre and post distillation process, double slope still is able to reduce the chemical concentrations in the bore hole water sample 3 done on 31st October, 2016 to low levels as presented in sample 2 for distilled water on 31st October, 2016. Although the double slope solar still is able to reduce coliform bacteria from a high level to lower level, it does not remove them completely as per the set Kenya standards maximum limits (KS 05-459 part 1 1996) and chlorination is advised to remove them.

4.11 Impacts of the double slope solar still to the environment

The use of solar irradiation brings about carbon savings and reduced pollution to the environment. The desalination replicates a natural process similar to evaporation and condensation thus has fewer impacts to the environment as no carbon dioxide or equivalent Green House Gases are released to the atmosphere. This can be quantified in terms of carbon credits which can be traded in open market. One carbon credit is equivalent to one tonne of carbon dioxide or its equivalent Green House Gases (GHG). Saleable credits are known as the certified emission reduction (CER) price which is equivalent to a tonne of CO_2 (t-CO_2e). The prices of CER or t-CO_2e are normally quoted in Euros (€) per tonne of CO_2 equivalent. The market of carbon trading value was € 25 per tonne during 2008 (Carbon credits, 2012). If the concept of carbon trading suggested under clean development mechanism (CDM) of the Kyoto Protocol, (2012) is included in the techno-economic analysis of the solar distillation system for developing countries, the unit cost of desalination of saline water will certainly reduce and become competitive with other technologies.

A 6 kWh/m^2/day of solar energy is equivalent to 0.6 litres/m^2/day of oil (Koschikowski, 2011). This means that the double slope solar still receiving 5.5 kWh/m^2/day is able to save 0.6 litres/m^2/day of oil. The concentrated brine as the byproduct of the processes can be disposed of by pouring it back to the source (ocean or borehole or a well) where sedimentation and other natural filtration will occur and remixing with brackish or sea water reducing the environmental impacts.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

As part of the objective of the study a double slope solar still was designed and fabricated in Kilifi climatic conditions, using block board of length 8 feet, 3 feet width and 0.75 inch thickness for the basin, an ordinary glass of 4 mm thickness for the glass cover at an inclination angle of 15^o.

The daily output of a double slope solar still depends on weather conditions and the amount of solar energy available. The fabricated double solar still is able to produce 1.652 litres/day/m^2 during the period which the study was conducted (September and October 2016).

Double slope solar still output was found to increase from 8 am to 4 pm as radiation, temperature and wind velocity increased. There is a strong correlation between double slope solar still output and solar irradiation and the equation $y = 0.103x^3 + 2.6938x^2 - 32.003x + 307.05$ (valid during the day where y represent solar still output in millimeters and x represent solar irradiation in MJ/m^2) where Rsq is 99.9% can be used to approximate solar still output where cumulative radiation is known. This cumulative solar irradiation is available in metrological stations all over the country and various counties.

The double slope still has an efficiency that ranges between 12 % to 20 % for a whole day sunny and below 12% if cloudy.

The water extracted from the collecting jar was expected to be within the bacteriological and mineralogical advised quantities. Under mineralogical advised quantities, it was found to be within the range but found to be bacteriological contaminated. The bacteriological contamination could have arisen from sanitation and handling of double slope solar still or environmentally trapped bacteria in the air. The water can be made safe for drinking by use of chlorination where chlorine is given freely at public health departments all over the coastal region. To improve mineral content; the distilled water can be remixed with other clean and safe drinking water like rain water.

The total cost of the double solar still is 90.78 USD and if production was done in large scale for commercial purpose the cost on labor and materials can be reduced due to economies of scale.

The LCC analysis shows that the double slope solar still has an NPV of Kshs 132,987 which is greater than zero hence the project is valid and economically feasible, Savings-to-Investment (SIR) is equal to 15 which is greater than one hence the savings will be more than investment cost and a pay-back period of 195 days to recover initial investment cost.

The results presented above show that the use of double slope solar still using brackish water is an economically viable and feasible measure for the improvement of the water quantity and quality in Kilifi and the surrounding coastal counties.

The study has also revealed that the cost per litre was Kshs 4.89 which ensures the acceptability of passive double slope solar still in rural and economically challenged areas since the retail market price for clean and safe bottle water in the region is Kshs 50 per litre. Considering the world recommended daily water consumption for an individual as 2 litres per day, it can be concluded that the double slope solar still with an area of one square meter is able to feed an individual during the cloudy and low sunny radiation conditions.

5.2 Recommendations

Based on the study information and on the estimates made, the recommended design for Kilifi county and surrounding coastal climatic condition is double slope solar still, with a north south facing glass cover inclined at an angle of 15º. The approximated efficiency is 12-20% with an output yield of 1.266 -1.652 litres/ m^2/day. The double slope solar still can be produced in large quantities to cater for clean water demands. This can be achieved if non-governmental organizations, national and counties government can fund the acquisition of the double slope solar stills.

5.3 Further research work

A study to be conducted to evaluate the amount of Electric energy needed to desalinate the same water under the same climatic and other study condition similar to the double slope solar still to be able to evaluate the cost of electric energy which can be used to determine the carbon saving to the environment (quantified in terms of carbon emissions in kilogrammes of Carbon dioxide). The carbon savings can be computed in terms of carbon credits to the project which can be traded in open market.

The modification needs to be done on design to improve the efficiency of the double slope still by either use of concentrating lenses, evacuated tubes, pre-heaters or to design a bigger system to increase clean water output.

A study to be carried to establish the best way to dispose off concentrated brine after the desalination process.

REFERENCES

Abdallah, S., Badran, .O. & Abu-Khader, M.M., (2008). Performance evaluation of a modified design of a single slope solar still. *Desalination*; *219*(1-3), 222-230.

Abdallah, S., & Badan O.O., (2008). Sun tracking system for productivity enhancement of solar still. *Desalination*; ***220,*** 669-776.

Abdel-Rehim, Z.S., & Lasheen, A., (2007). Experimental and theoretical study of a solar desalination system located in Cairo, Egypt. *Desalination*; *217*, 52-64.

Al-Shuaib, A., Al-bahu,M., El-Dessouky, H. & Ettouney, H., (1999). Progress of desalination industry in Kuwait. *IDA world congress on desalination and water reuse conference proceeding;* San Diego, USA: pp 191-221.

Akash, B. A., Mohsen, M. S. and Nayfeh, W., (2000). Experimental study of the basin type solar still under local climate conditions. *Energy Conversion and Management; 41*(9), 83-890.

Al-Hayek, I., and Badran, O.O., (2004). The effect of using different designs of solar stills on water distillation. *Desalination*; ***169***, 121-127

Al-Hinai, H., Al-Nassri, M. S., and Jubran, B. A., (2002). Parametric investigation of a double effect solar still in comparison with a single-effect solar still. *Desalination*; ***150***(1), 75-83.

Al-Karaghouli, A. A., & Minasian, A. N., (1995). A floating-wick type solar still. *Renewable Energy*; ***6***(1), 77-79.

Al-Rqobal, H. & Al-Munayyis, A. (1989). A recarbonation process for treatment of distilled water by MSF plants in Kuwait. *Desalination;* ***73***, 295–312.

Anil, K. R., & Tiwari, G.N., (2005). Effect of the condensing cover's slope on internal heat and mass transfer in distillation: an indoor simulation. *Desalination*; ***180***. 73-88.

Argaw, N., (2001). *Renewable Energy in Water and Wastewater Treatment Applications.*, Colorado, USA: National Renewable Energy Laboratory.

Armenta–Deu C., (1997). Increasing the evaporation rate for fresh water production. *Application for energy savings in renewable energy sources;* ***11***(2), 197-209.

Arnell, N., (2000). *Hydrology and global environmental change*, Harlow, UK Pearson Education publisher.

Aybar, H.S., Egelioglu, F., & Atikol, U., (2005). An experimental study on an inclined solar distillation system, *Desalination*, ***180,*** 285-289.

Ayoub, G. M., & Malaeb, L., (2012). Developments in Solar Still Desalination Systems: A Critical Review. *Critical Reviews in Environmental Science and Technology*; ***42***, 2078–2112.

Badran, O., Beithou, N., Al Alawin, A., Awad, A., Abdelhadi, Y. & Al-Mofleh, A., (2013). Experimental Study of a Vacuumed Solar Still System. *International Journal of Applied Power Engineering*; ***2***, 99-104.

Badran, O.O., & Abu-Khader, M.M., (2007). Evaluating thermal performance of a single slope solar still. *Heat Mass transfer;* ***43***, 985-995.

Badran, A.A., Al-Hallaq, A.A., Eyal Salman. I.A., & Odat .M.Z., (2005). A solar still augmented with a flat-plate collector. *Desalination*; ***172***, 227-234.

Badran, O.O., & Al-Tahaineh, H.A., (2005). The effect of coupling a flat-plate collector on the solar still productivity. *Desalination*; ***183***, 137-142.

Boukar, M., & Harmim, A., (2004). Parametric Study of a vertical solar still under desert climatic conditions, *Desalination;* ***168***, 21-28.

Carbon credits, (2012). http://www.carbon futures.org/index.php/carbon creditsexplained.html

Connor, D. W., (1980). Solar Energy Technology Handbook Part A, *Low-Temperature Sensible Heat Storag*, Marcel: Dekker Incorporated.

Dieter, G. E., (1989). *Mechanical metallurgy, SI Metric adaptation*. Maidenhead, UK; McGraw-Hill Education.

Dimri, V., Sarkar, B., Singh, U. & Tiwari, G., (2008). Effect of condensing cover material on the yield of an active solar still: An experimental validation. *Desalination*; ***227,*** 178–189.

Dwivedi, V.K., & Tiwari, G.N., (2008). Annual energy and exergy analysis of single and double slope passive solar stills. *Applied Science Research*; ***3***(3), 225–241.

El-Bahi, A., & Inan .D. (1999). Analysis of a parallel double glass solar still with a separate condenser. *Renewable Energy;* ***17***, 509-2.

El-Sebaii, A., (2000). Effect of wind speed on some designs of solar stills. *Energy Conversion and Management*; ***41***, 523–538.

El-Sebaii, A.A., Ramadan, .M.R.I., Aboul-Enein, S., & Salem, .N., (2008). Thermal performance of a single-basin solar still integrated with a shallow solar pond. *Energy Conversion and Management*; ***49***, 2839-48.

Fath, H.E.S., El-Samanoudy, M., Fahmy, K., & Hassabou A., (2003). Thermal-economic analysis and comparison between pyramid shaped and single-slope solar still configurations. *Desalination*; ***159***, 69-79.

Fath, H., & Ghazy. A., (2002). Solar desalination using humidification-dehumidification technology, *Desalination*, ***142***, 119–133.

Fath, H. & Hosny, H. (2002). Thermal performance of a single-sloped basin still with an inherent built-in additional condenser, *Desalination*; ***142***, 19–27.

Fath, E.S.H., (1998). Solar distillation: a promising alternative for water provision with free energy, simple technology and a clean environment. *Desalination*, ***1***(166), 45–56.

Gabbrielli, E. (1981). A tailored process for remineralization and potabilization of desalinated water. *Desalination*, ***39***, 503–520.

Garg, H.P., & Prakash, J., (2000). *Solar Energy Fundamentals and Applications*, New Delhi: Tata McGraw-Hill.

Garg, H.P., & Mann, H.S., (1976). Effect of climatic, operational, and design parameters on the year round performance of single-sloped and double-sloped solar still under Indian arid zone conditions. *Journal of Solar Energy*; ***18***(2), 159-164.

Gordes, H.M.J., (1985). *Understanding solar stills*. Technical reviewers: Daniel Dunha Jacques Le Normand Darrell G.Phippen, Published by Volunteers in Technical Assistance (VITA) 1815 North Lynn Street, Suite200 Arlington, 1985, Virginia 22209 USA; pp 15-17.

Govind, J., & Tiwari, G.N., (1984). Economic analysis of some solar energy systems. *Energy Conversion and Management*; ***24***, 131-135.

Hamed, O.A., Eisa, E.I., & Abdalla, W.E., (1993). Overview of solar desalination, *Desalination;* ***93***, 563-579.

Hasson, D., & Bendrihem, O., (2006). Modelling remineralization of desalinated water by limestone dissolution. *Desalination.* ***190,*** 189-200.

Ismail, B.I., 2009). Design and performance of a transportable hemispherical solar still. *Renewable Energy*, ***34,*** 145-150.

Kabeel, A.E., & El-Agouz, S.A., (2011). Review of researches and developments on solar stills. *Desalination*; ***276***, 1-12.

Kenya Meteorological Department, (2018). Kilifi County historical data. Retrieved from: http://kmddl.meteo.go.ke:8081/maproom/Climatology/index.html

Khalifa, A.J.N., (2010). On the effect of the cover tilt angle of the simple solar still on its productivity in different seasons and latitudes. *Energy Conversion and Management*; ***52***, 431-436.

Khawaji, A.D. & Wie, J.M. (1994). Potabilization of desalinated water at Madinat Yanbu Al-Sinaiyah. *Desalinatio*, ***98***, 135–146.

Kilifi County, (2013). *Kilifi County First County integrated development plan 2013-2013.* Kilifi: Kilifi County.

Kirby, H.A. (1987). The Dubai E Power Generation and Desalination Station. *ASME COGEN-TURBO International Symposium on Turbomachinery, Combined-Cycle and Cogeneration*, New York, USA, pp. 9–16.

Kolstad, C., (2014). *Desalination of Groundwater by Solar Stills Field Trials in Afghanistan.* Unpublished Master's Thesis, Norway: Norwegian University of Life Science;

Koschikowski Joachim, (2011).When and Where Will it Make Sense?; *Water Desalination:* Fraunhofer Institute for Solar Energy Systems Germany: ISE Freiburg.

Kudish, A.I., Gale, J., & Zarmi, Y., (1986). Solar desalination in conjunction with controlled environmental agricultural in arid zones. *Energy Conversion and Management*; ***26***, 201.

Kumar, S., & Tiwari, G.N., (2009). Life cycle cost analysis of single slope hybrid (PV/T) active solar still. *Applied Energy*; ***86***. 1995-2004.

Kutty, P.C.M., Nomani, A.A., & Thankachan, T.S. (1991). Evaluation of Water Quality Parameters in Drinking Water from SWCC MSF Plants.

Proceedings of the IDA World Conference on Desalination and Water Reuse, Washington DC, USA, **1**, pp. 1-14.

Kyoto Protocol Clean development mechanism, (2012). United Nations Framework Convention on Climate Change Retrieved from: http://unfccc .int/ resource/docs/convkp/kpeng.pdf

Liberman, B. & Liberman, I. (1999). A post treatment computer program", *Desalination and Water Reuse*, ***9***(2), 51–55.

Ludwig, H. & Hetscel, M. (1986). Treatment of distillates and permeates from seawater desalination plants. *Desalination*, ***58,*** 135–324.

Malik, M.A.S., Tiwari G.N., & Kumar, A., (1982). Solar Distillation*: A Practical Study of a Wide Range of Stills and their Optimum Design, Construction and Performance*. UK: Pergamon Press.

Madhlopa , A., & Clarke, J.A., (2011). Theoretical study of the aspect ratio of a solar still with double slopes in proceedings of world renewable energy Congress 2011, Linkoping Sweden.

Meukam, P., Njomo D., Gbane, A. & Toure, S., (2004). Experimental optimization of a solar still application to alcohol distillation*. Chemical Engineering and Processing; **43,*** 1569–1577.

Mwamburi, K.E. (2012). *Factors affecting access to water supply in Kisauni area, Mombasa county, Kenya.* Unpublished Masters Thesis. Nairobi: University of Nairobi.

Munga, D., (2002). *Freshwater Shortage and Groundwater Quality in Mombasa*, Mombasa: KMFRI.

Murugavel, K., Chockalingam, K. K., and Srithar, K., (2008).Progresses in improving the effectiveness of the single basin passive solar still. *Desalination*; ***220***(1), 677-686.

Musingi, J. K., Kithiia, S.M. & Wambua, B.N., (1999). Impacts of Urban Growth on Surface Water and Ground Water Quality, (Proc. Of IUGG 99 Symposium HS5, Birmingham, July 1999), IAHS Publication no 259, 419,-422, Wallingford, Oxfordshire OX108BB, UK.

Naim, M.M. and Abd El-Kawi, M., (2003). Non-conventional solar stills with charcoal particles as absorber medium. *Desalination*; ***153***, 55–64.

Nafey, A.S., Abdelkader, M., Abdelmotalip, A. and Mabrouk, A.A. (2000). Parameters affecting solar still productivity. *Energy Conversion and Management*. ***41***, 1797-1809.

Ray, C., & Jain, R., (2011). *Drinking water treatment: focusing on appropriate technology and sustainability.* (2nd Eds.), Netherland: Springer s.

Ruggieri, F., Fernadnez-Turiel, J.L., Gimeno, D., Valer, F., García, J.C. & Medina, M.E., (2008). Limestone selection criteria for EDR water re mineralization. *Desalination; **227**,* 314-326.

Sadineni, S.B., Hurt .R., Halford, C.K.,& Boehm, R.F., (2008). Theory and xperimental investigation of a weir-type inclined solar still. *Energy*; ***33***, 71-80.

Samee, M.A., Mirza, U. K., Majeed, T., & Ahmad, N., (2007). Design and performance of a simple single basin solar still. *Renewable and Sustainable Energy Reviews **11***, . 543–549.

S.O.K., (2012). Kenya Counties Map, Scale 1:2,500,000 ‘Series SKNSDI 1’, Kenya.

Solanki Chetan Singh, (2009). *Renewable Energy Technologies* A practical guide for beginners, Eastern Economy Edition, New Delhi: PHI Learning Pvt. Ltd.

Sukhatme, S.P., (1987). *Solar energy: the principle of thermal collection and storage*, (3rd edition) , New Delhi: Tata Mc Graw Hill.

Tiwari, G.N., (2011). *Solar Energy Fundamentals, Design, Modelling and Applications*, , New Delhi, Indi Narosa Publishing House a.

Tiwari, A.K., and Tiwari, G.N., (2007). Thermal modelling based on solar fraction and experimental study of the annual and seasonal performance of a single- basin solar still: the effect of water depths. *Desalination**; 207*, 184-204.

Tiwari, G.N., and Singh, H.N., (2004). Solar distillation. *Solar Energy Conversion and Photoenergy Systems;* ***1***(2), 93-95.

Tiwari, G.N., Singh, H.N., and Tripathi, R., (2003).Present status of solar distillation. *Solar Energy*; ***75***(5), 367-373.

Tripathi, R., and Tiwari, G. N., (2004). Performance evaluation of a solar still by using theconcept of solar fractionation. *Desalination*; ***169***(1), 69-80.

Twidell, J., and Weir, T., (2006). *Renewable Energy Resources*, (2nd edition), Park Square, Milton Park, Abingdon, London, UK : Taylor and Francis,.

Valsaraj, P., (2002). An experimental study on solar distillation in a single slope basin still by surface heating the water mass, *Renewable Energy*, ***25***, 607–12.

Velmurugan, V., & Srithar, K., (2011). Performance analysis of solar stills based on various factors affecting the productivitya review. *Renewable and Sustainable Energy Reviews*; ***15***(2) 1294-1304.

UN News Service,(2009). Majority of world population face water shortages unless action was taken, Retrieved from: http://www.un.org/apps/news/story.asp?NewsID=29796&Cr=water&Cr1=agr

Velmurugan, V., Deenadayalan , C.K., Vinod, H.,and Srithar, K., (2008). Desalination of effluent using fin type solar still. *Energy*; **33**:1719-1727.

Velmurugan, V., Gopalakrishnan, M., Raghu, R., & Srithar K., (2008). Single basin solar still with fin for enhancing productivity. *Energy Conversion and Management;* ***49*** , 2602–2608.

Velmurugan, V., Kumaran, S.S., Prabhu,V.N., & Srithar, K., (2008). Productivity enhancement of stepped solar still performance analysis. *Thermal Science*; ***12***, 153-163.

Velmurugan, V., & Srithar .K., (2007). Solar stills integrated with a mini solar pond analytical simulation and experimental validation. *Desalination*; ***216***, 232-241.

Ward, R.C., and Robinson, M., (2000). *Principles of hydrology*. (4th edition)., London: McGraw Hill

WHO, (2015). Water sanitation health/monitoring. Retrieved from: at:http://www.who.int/water sanitation_health/monitoring/jmp 2015 key facts/en/

WHO (2011) Guidelines for Drinking-water Quality. (4th ed.), Retrieved from: http://whqlibdoc.who.int/publications/2011/9789241548151eng.pdf

WHO (2004), *Water requirements, impinging factors and recommended intakes.* Geneva, Switzerland, Retrieved from: www.who.int/water sanitation health/dwq/nutrientsindw.pdf

WHO (2004), KMFRI. Geneva, Switzerland.

WHO. (2001) Water for a Health-Taking charge. Geneva: World Health Organization, Retrieved from http://www.who.int/water sanitation health/wwdreport.pdf?

World Health Organization (1979). *Health effects of the removal of substances occurring naturally in drinking-water with special reference to demineralized and desalinated water*. EURO Reports and Studies, **16**, pp. 1-24, Retrieved from: http://docs.watsan.net/Scanned_PDF _Files/ Class_Code_2_Water/250-79HE 5721.pdf

Wolpert, L. J., (2003). Solar Powered Ejector Air Conditioning System for Mexican Climate. Unpublished PhD Thesis, UK: University of Nottingham.

World Water Organization, (2010). Water Facts and Water Stories from Across the Globe,Retrieved from: http://www.theworldwater.org/waterfacts.php

Yamauchi, Y., Tanaka, K., Hattori, K., Kondo M. & Ukawa, N. (1987). Remineralization of desalinated water by limestone dissolution filter. *Desalination**, 66,*** 365–383.

Zein, M., & Al-Dallal., (1984). Solar desalination correlation with meteorological parameters. In 2nd ArabInternational conference. pp. 288.

APPENDICES

Appendix 1: Double slope solar still views

Double slope Solar still

Double slope Solar still

Appendix 2: Double slope solar still views

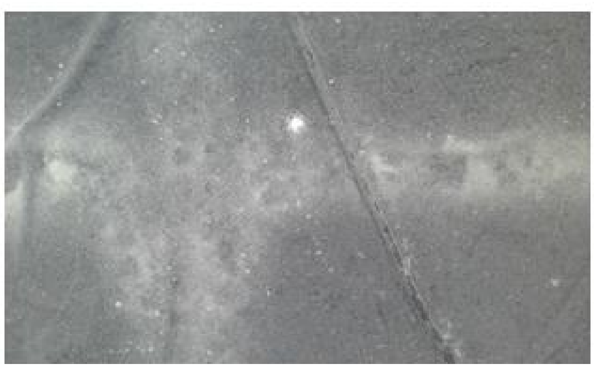
Double slope solar still

Double slope solar still

Appendix 3: Double slope solar still views

Double slope solar still

By product of solar still (salt)



Appendix 4: Water analysis Equipment (PH) in government laboratory Mombasa

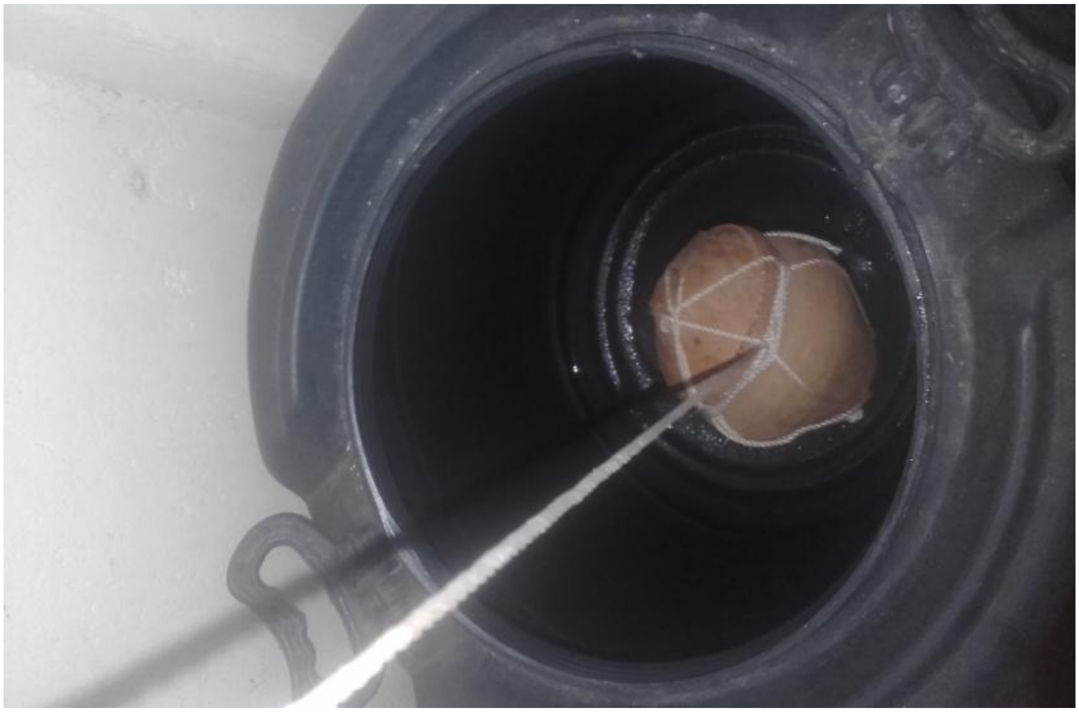
Appendix 5: Manual cleaning work is done on the double slope solar still

Appendix 6: Storage tank for Brackish water

Appendix 7: Data collection on solar irradiation and dry bulb temperatures

Appendix 8: Study area in Kilifi County Mtwapa agro metrological station

Appendix 9: Chlorination process



Appendix 10: Government chemist lab results-processed water bacteria analysis

REPUBLIC OF KENYA

GOVERNMENT CHEMIST'S DEPARTMENT
P.O. BOX 81119-80100, TEL; 473951/2
MOMBASA.

BACTERIOLOGICAL EXAMINATION OF WATER

Lab. Ref. No: BW/VOL.IX/140/2016/60 **Sender's Ref:**

Time and date sample taken: 10.40 am 21/9/2016

Time and date sample examined: 02.00 pm 23/9/2016

Taken By: Benson

Authority: Benson Mobile no.0724393407

Reason for sampling: Bacteriological Analysis **(If water is suspected of causing ill health please say so)**
Source of sample: Processed Water **(state if well, spring, borehole, stream or public supply)**

Is it protected? Yes

If so how? **(Is it completely covered, or sides only)**

Is there a pump? No

If so, how long has it been in use? -

Has it been overhauled recently? -

Exact site sample taken from: Tap

(That is, tap, in kitchen, through cistern or direct from mains)

Are there any latrines or other sources of pollution? NO

If so, where? -

Is it chlorinated supply? Desalination

Report:

Total Coliforms Count (MPN/ 100ml)	>2400 (Max Limit =NIL)
Faecal Coliforms (E. Coli) count (MPN/ 100ml)	53 (Max Limit =NIL)
Total plate Count (37°c, 48 Hrs)	48 cfu/ml (Max Limit=20/ml
Strept.faecalis	-

DATE: 27/9/2016

Mwabwagizo Juma
Government chemist/ Analyst

Appendix 11: Government chemist lab results-processed water chemical analysis

REPUBLIC OF KENYA

GOVERNMENT CHEMIST'S DEPARTMENT
P. O. BOX 81119-80100MOMBASA TEL. 473951/52

REPORT ON CHEMICAL ANALYSIS OF WATER

Report Reference: WQ.1/VOL.V/52/2016
Lab Sample No:159/2016 **Date Received: 31/10/2016**
Sender: Benson Karanja
Source: Solar still channel
RESULTS
Colour:16Hazen Unit **Turbidity:**16.2 NTU
Deposit: Nil **Odour:**Unobjectionable
Taste: -
Electrical Conductivity at 25^{0}C (Micro ohms/cm^3)375 (2500)

TYPE OF CHEMICAL ANALYSIS	PARTS PER MILLION (mg/L)	MAXMUM LIMIT (PPM)
Free Carbon Dioxide	1.0	-
Free Saline Ammonia Nitrogen (N)	-	0.5
Phosphate PO^{-3}_4	0.1	2.2
Fluorides	-	1.5
Oxygen Absorbed, Four hours 27^{o}C(O)	0.8	1
Alkalinity as $CaCO_3$...Phenolphthalein (Carbonate)	Nil	-
Methyl Orange (Bicarbonate)	16.0	300
Carbonate hardness as calcium carbonate ($CaCO_3$)	-	300
Non-Carbonate Hardness as Calcium Carbonate ($CaCO_3$)	-	
Chloride (Cl^-)	8.0	250
nitrate (NO^{3-}-N)	0.4	35
Heavy Metals (Cu)	-	2
Sodium (Na)	2.0	200
Potassium (K)	2.0	100
Calcium (Ca)	1.7	150
Magnesium (Mg)	1.9	100
Total Dissolved solids, Residue dries at 180^{o}C	26.0	1000
pH	6.7	6.5 – 8.5

REMARKS

The water complies with the shown standards as per the parameters tested.

GOVERNMENT ANALYST MOMBASA

Mwabwagizo Juma
GOVERNMENT ANALYST

Date:*03/11/2016*

Appendix 12: Government chemist lab results-Brackish water chemical analysis

REPUBLIC OF KENYA

GOVERNMENT CHEMIST'S DEPARTMENT
P. O. BOX 81119-80100MOMBASA TEL. 473951/52

REPORT ON CHEMICAL ANALYSIS OF WATER

Report Reference: WQ.1/VOL.V/50/2016
Lab Sample No: 158/2016 **Date Received: 31/10/2016**
Sender: BensonKakanja
Source: Borehole
RESULTS
Colour:10**Hazen Unit** **Turbidity:**0.54 NTU
Deposit: Nil **Odour:**Unobjectionable
Taste: -
Electrical Conductivity at 25^{0}C (Micro ohms/cm^3)972 (2500)

TYPE OF CHEMICAL ANALYSIS	PARTS PER MILLION (mg/L)	MAXMUM LIMIT (PPM)
Free Carbon Dioxide	50	-
Free Saline Ammonia Nitrogen (N)	-	0.5
Phosphate PO^{-3}_4	0.41	2.2
Fluorides	-	1.5
Oxygen Absorbed, Four hours 27°C(O)	0.8	1
Alkalinity as $CaCO_3$ ...Phenolphthalein (Carbonate)	Nil	-
Methyl Orange (Bicarbonate)	380	300
Carbonate hardness as calcium carbonate ($CaCO_3$)	-	300
Non-Carbonate Hardness as Calcium Carbonate ($CaCO_3$)	-	
Chloride (Cl^-)	84	250
nitrate (NO^{3-}-N)	0.5	35
Heavy Metals (Cu)	-	2
Sodium (Na)	69	200
Potassium (K)	03	100
Calcium (Ca)	0.38	150
Magnesium (Mg)	2.31	100
Total Dissolved solids, Residue dries at 180°C	660	1000
pH	6.9	6.5 – 8.5

REMARKS:
The water complies with the shown standards as per the parameters tested.

GOVERNMENT ANALYST MOMBASA

Mwabwagizo Juma
GOVERNMENT ANALYST

Date:*03/11/2016*

Appendix 13: Government chemist lab results-processed water bacteria analysis

REPUBLIC OF KENYA

GOVERNMENT CHEMIST'S DEPARTMENT
P.O. BOX 81119-80100, Tel. 041-4470107/0717-323890
MOMBASA.
BACTERIOLOGICAL EXAMINATION OF WATER

Lab. Ref. No: BW/VOL.XXV/726/2016/376 **Sender's Ref**:

Time and date sample taken: 2.00 pm 31/10/2016
Time and date sample examined: 2.00 p.m. 04/11/2016

Taken By: Benson
Authority: Benson Tel: No. 0724-393407

Reason for sampling: Bacteriological Analysis **(if water is suspected of causing ill health please say so)**

Source of sample: Solar Still Collection Channel (Fresh) **(state if well, spring, stream or public supply)**

Is it protected? Yes

If so how? (Is it completely covered, or sides only)

Is there a pump? No

If so, how long has it been in use?

Has it been overhauled recently?

Exact site sample taken from: (whether from kitchen, taps, mains, cisterns etc.)
Are there any latrines or other sources of pollution? No

If so, where? -

Is it chlorinated supply? No

REPORT:

Total Coliform Count (MPN/ 100ml)	>2400
Faecal Coliform (E. Coli) count (MPN/ 100ml)	3
Total plate Count (37^{o}c, 48Hrs)	
Strept. faecalis	

REMARKS:
The water is contaminated with coliforms. Chlorination is recommended before use

Juma Mwabwagizo
GOVERNMENT ANALYST

GOVERNMENT ANALYST
MOMBASA

Date: 8th November, 2016

/lm

Appendix 14: Government chemist lab results-Brackish water bacteria analysis

REPUBLIC OF KENYA

GOVERNMENT CHEMIST'S DEPARTMENT
P.O. BOX 81119-80100, Tel. 041-4470107/0717-323890
MOMBASA.
BACTERIOLOGICAL EXAMINATION OF WATER

Lab. Ref. No: BW/VOL.XXV/725/2016/375 **Sender's Ref.**

Time and date sample taken: 2.00 pm 31/10/2016
Time and date sample examined: 2.00 p.m. 04/11/2016

Taken By: Benson
Authority: Benson Tel: No. 0724-393407

Reason for sampling: Bacteriological Analysis **(if water is suspected of causing ill health please say so)**

Source of sample: Borehole **(state if well, spring, stream or public supply)**

Is it protected? Yes

If so how? **(Is it completely covered, or sides only)**

Is there a pump?

If so, how long has it been in use?

Has it been overhauled recently?

Exact site sample taken from: **(whether from kitchen, taps, mains, cisterns etc.)**

Are there any latrines or other sources of pollution?

If so, where? -

Is it chlorinated supply? No

REPORT:

Total Coliform Count (MPN/ 100ml)	>2400
Faecal Coliform (E. Coli) count (MPN/ 100ml)	16
Total plate Count (37°c, 48Hrs)	
Strept. faecalis	

REMARKS:
The water is contaminated with coliforms. Chlorination is recommended before use

Juma Mwabwagizo
GOVERNMENT ANALYST

Date: 8th November, 2016

/lm

GOVERNMENT ANALYST
MOMBASA

Appendix 15: Cost comparison of different solar stills

No.Ref	Type of solar still	Area m^2	Climatic	Daylight hours	P	CRF	FAC	S	SFF	ASV	AMC	AC	M	CPL
Fath *et al.*,2003	Single slope	1527	Egypt	6-8	275	0.177	49	55	0.057	3.5	7.5	53	1511	0.035
Samee *et al.*,2007	Single slope	0.54	Pakistan		190	0.177	34	38	0.057	2	5	37	585	0.063
Kumar& Tiwari , 2004	Single slope	1	India	10-19	250	0.177	44.2	50	0.057	3	6.6	47.8	343	0.14
Kumar& Tiwari, 2004	With solar collector	1	India	9-17	1144	0.177	202.5	228.8	0.057	13	30.4	219.9	1203	0.18
Badran& Tahaineh, 2005	With solar collector	1	Jordan	9-17	480	0.177	85	96	0.057	5.5	15.3	93	806	0.115
Abdel-Rehim &Lasheen, 2007	With solar concentrator	1	Egypt	8-18	300	0.177	53.1	60	0.057	3.4	8	57.7	990	0.058
Abdallah & Badran, 2008	With sun tracking	1	Jordan	9-19	300	0.177	53.1	60	0.057	3.4	8	57.7	250	0.23
Fath *et al.*, 2003	Pyramid shaped	1.527	Egypt	7-18	250	0.177	44	5050	0.057	3	7	48	1533	0.031
Al-Hinai *et al.*, 2002	Pyramid shaped	1	Oman	6-18	106	0.177	18.7	19	0.057	1.1	2.8	20.4	1511	0.0135
Badran *et al.*, 2005	Pyramid with collector	0.922	Jordan	8-20	450	0.177	79.6	90	0.057	5	12	86.7	844	0.103

Velmurugan *et al.*, 2008	With fin type	1	India	8-17	200	0.177	36	40	0.057	2.5	5.5	39	720	0.054
Velmurugan *et al.*, 2008	With wick and fin type	1	India	9-17	250	0.177	44.3	50	0.057	3	6.6	47.9	731	0.065
Ismail, 2009	Transportable hemispherical	0.5	Canada	9-17	958	0.177	170	191.6	0.057	11	25.5	184.5	1026	0.18
Velmurugan *et al.*, 2008	Stepped with fin and sponges	0.5	India	9-17	180	0.177	32	36	0.057	2	4.8	34.8	546	0.064
Abdallah *et al.*, 2008	Stepped with sun tracking	0.48	Jordan	8-18	350	0.177	62	70	0.057	4	10	68	958	0.071
Sadineni *et al.*, 2008	A weir type	0.969	USA	8-22	280	0.177	50	56	0.057	3.2	7.5	54.3	1001	0054
Velmurugan &Srithar, 2007	With sponge and pond	1	India	8-17	350	0.177	62	70	0.057	4	9.3	67.3	837	0.08
Elsebaii *et al.*, 2008	With shallow solar pond	1	Egypt	8-18	320	0.177	56.6	64	0.057	3.65	8.5	61.45	1183	0.052
El-Bahi &inan, 1999	With separate condenser	1	Turkey	8-18	350	0.177	62	70	0.057	4	9.3	67.3	1116	0.06

(Kabeel & El-Agouz, 2011)

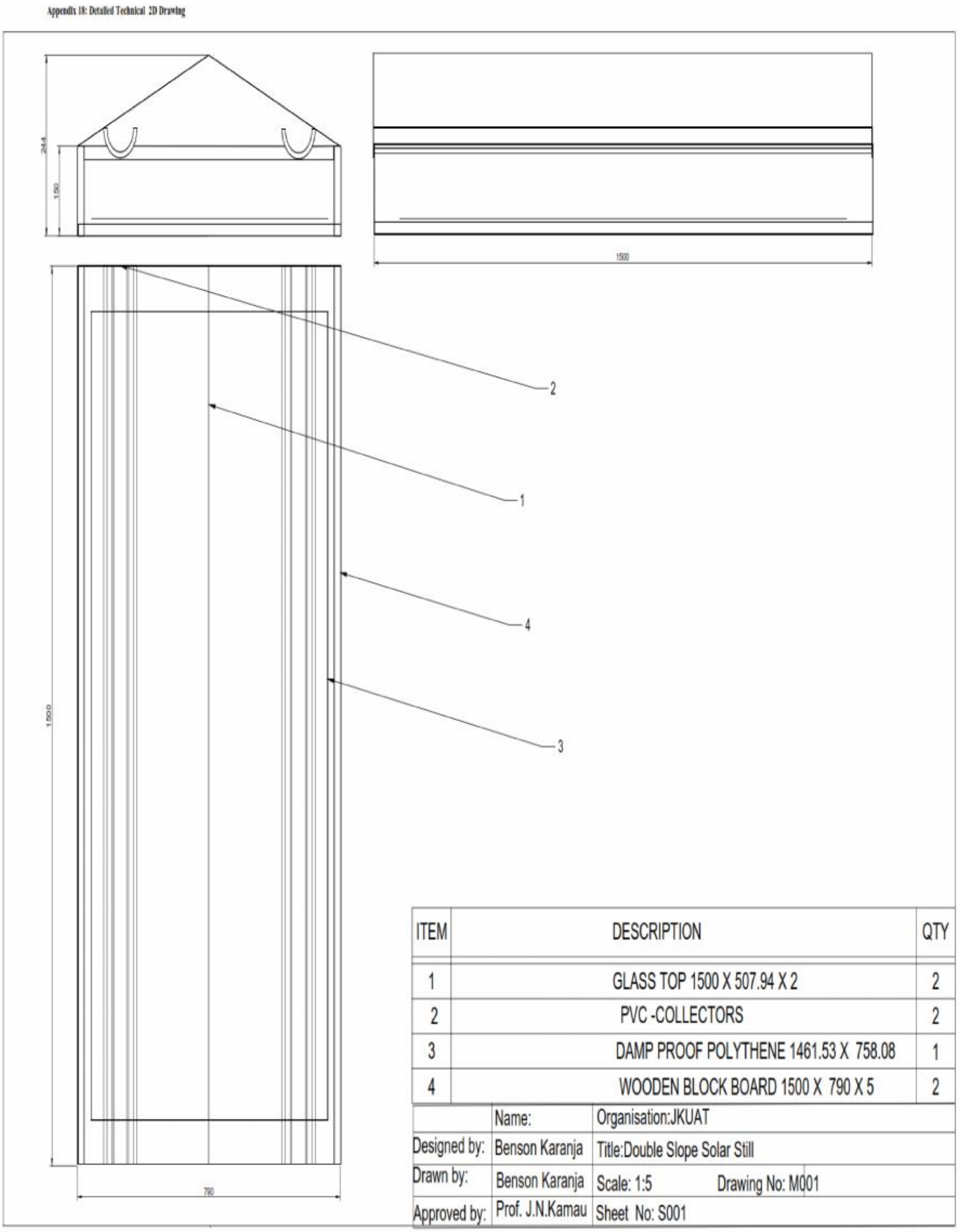
Appendix 16: Life cycle cost analysis of double slope solar still

Discount rate(in decimal points)	**0.040**										
Annual savings in Kshs	17548.84										
Analysis period	**10 years**										
Residual value in Kshs	**0**										
Life Cyle Investments	9350										
Multiplying factor	0.961538462										
Year	0	1	2	3	4	5	6	7	8	9	10
Annual savings	0	17549	533	533	533	533	533	533	533	533	533
Pv annual savings	0	16,874	16,225	15,601	15,001	14,424	13,869	13,336	12,823	12,330	11,855
Total sum PV annual savings	**142337**										
Year	0	1	2	3	4	5	6	7	8	9	10
PV Life Cycle Investments	9350	0	0	0	0	0	0	0	0	0	0
Total sum PV Life Cycle Investments	**9350**										
Net cash flow	9350	17548	17548	17548	17548	17548	17548	17548	17548	17548	17548
Net Present Value in kshs	**Kshs 132,987**										
Saving to Invest Ratio	**15**										
Simple Pay Back Period	**0.5**										
The Internal Rate of Return	249.2										

Appendix 17: Economic analysis for the fabricated double slope solar still

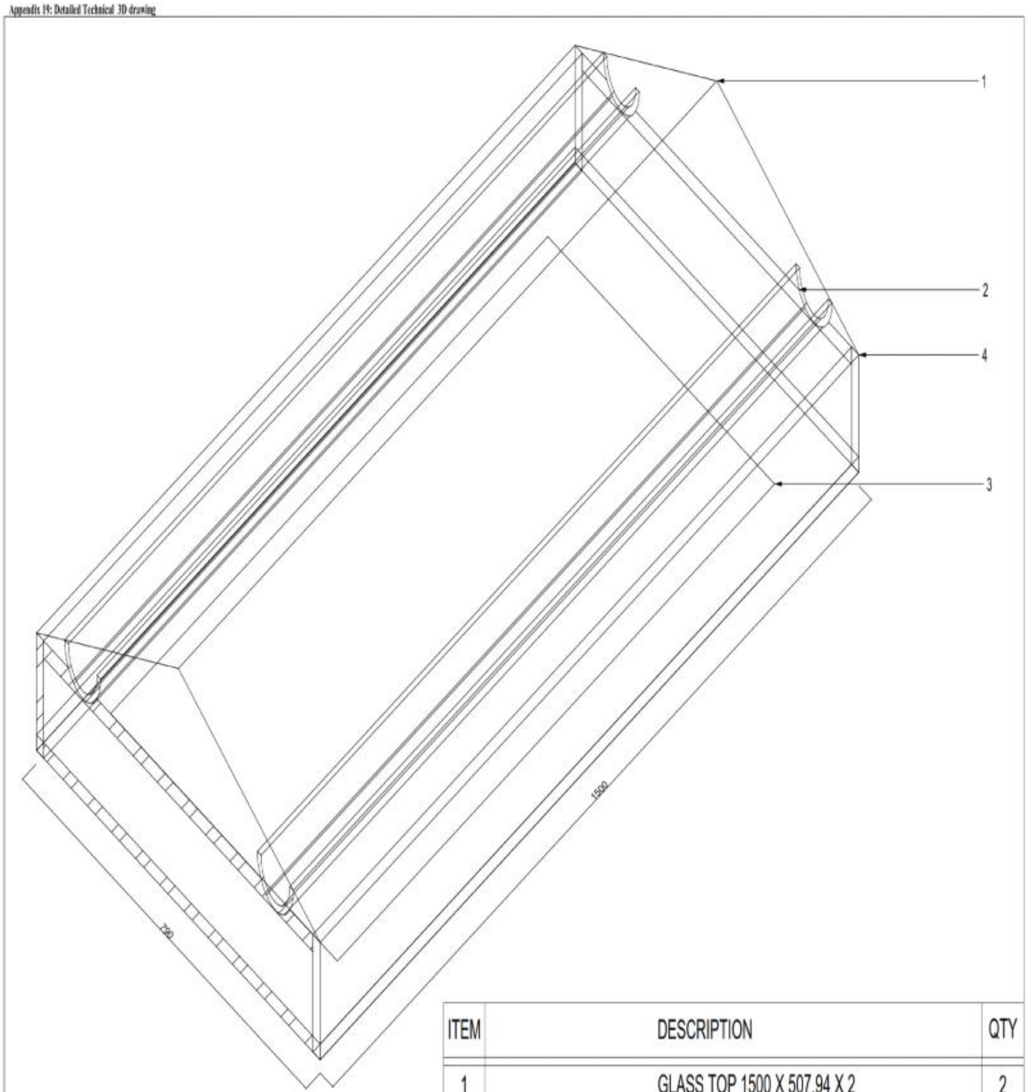
	Designed double solar still with S =0.35P	designed double solar still with S=0.2P(USD$)	Fath *et al.,* 2003	samee *et al.,* 2007	Kumar and Tiwari, 2004
Average daily yied in litres	0.962	0.962	0.962	0.962	0.962
Annual yield in litres	351.13	351.13	1511	585	343
interest rate	0.12	0.12	0.12	0.12	0.12
Maintenance and Operation cost	15%	15%	15%	15%	15%
Useful life in years	10	10	10	10	10
Salvage value	35%	20%	20%	20%	20%
CRF	0.177	0.177	0.177	0.177	0.177
SFF	0.057	0.057	0.057	0.057	0.057
P	9350	9350	275	190	250
S	3272.5	1870	55	38	50
FAC	1654.95	1654.95	48.675	33.63	44.25
ASV	186.5325	106.59	3.135	2.166	2.85
AMC	248.2425	248.2425	7.30125	5.0445	6.6375
Annual Cost/Yield	1716.66	1796.6025	52.8412	36.508	48.0375
M	351.13	351.13	1511	585	343
CPL	0.04746561	0.050	0.035	0.062	0.140

Appendix 18: Technical drawing of the designed double slope solar still



Appendix 19: Isometric views

Appendix 19: Detailed Technical 3D drawing



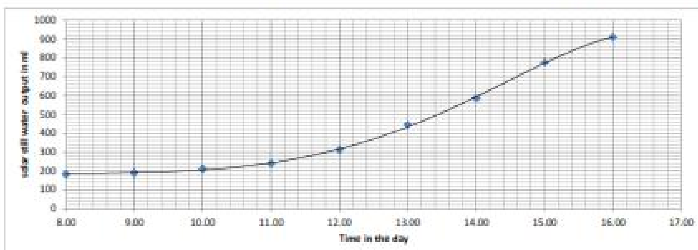
ITEM	DESCRIPTION	QTY
1	GLASS TOP 1500 X 507.94 X 2	2
2	PVC -COLLECTORS	2
3	DAMP PROOF POLYTHENE 1461.53 X 758.08	1
4	WOODEN BLOCK BOARD 1500 X 790 X 5	2

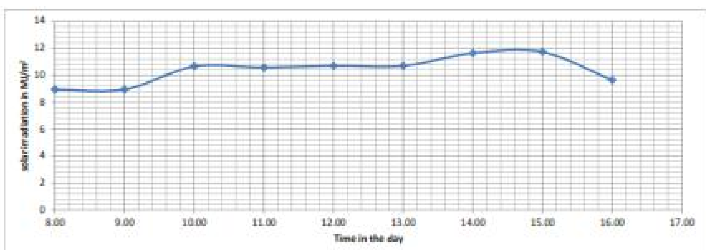
	Name:	Organisation:JKUAT	
Designed by:	Benson Karanja	Title:Double Slope Solar Still	
Drawn by:	Benson Karanja	Scale: 1:5	Drawing No: M002
Approved by:	Prof.J.N Kamau	Sheet No: S002	

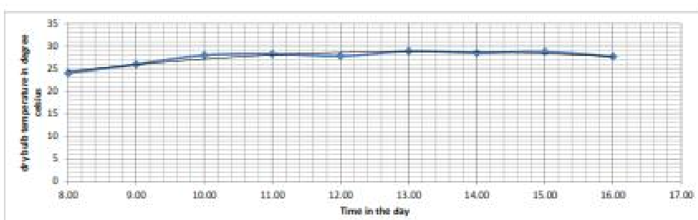
Appendix 20: Data and graph for various days

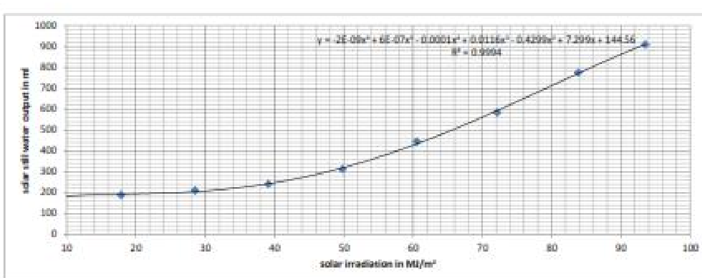
10th september 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation((MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	183.75	183.75	8.94	8.94	24	5	94	cloudy	nil
9.00	6.25	190	8.94	17.88	26	7	76	sunny	nil
10.00	21.25	211.25	10.65	28.53	28	3	64	cloudy	nil
11.00	30	241.25	10.57	39.1	28.3	10	62	sunny	nil
12.00	71.25	312.5	10.7	49.8	27.8	13	63	sunny	nil
13.00	133.75	446.25	10.7	60.5	28.9	10	61	sunny	nil
14.00	138.75	585	11.64	72.14	28.5	10	61	sunny	nil
15.00	191.25	776.25	11.72	83.86	28.8	10	59	sunny	nil
16.00	133.75	910	9.63	93.49	27.7	6	65	sunny	nil





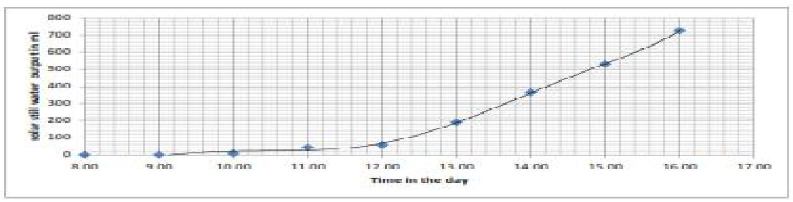


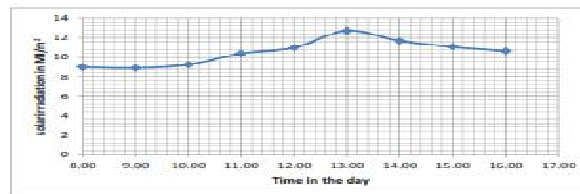


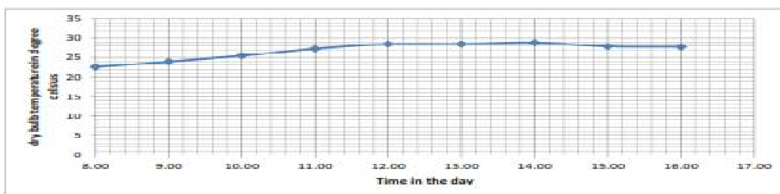
Appendix 20 Data and graphs for various days

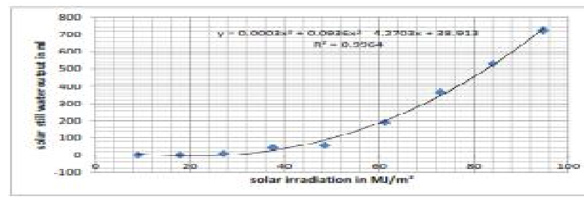
20th September 2016

Time	still output (ml)	cumulative solar still output in ml	solar irradiation(MJ/m2)	cumulative solar irradiation(MJ/m2)	dry bulb temperature	wind velocity	relative humidity	weather sky	rainfall(mm)
8.00	0	0	8.99	8.99	22.6	5	88	cloudy	nil
9.00	0	0	8.9	17.89	24	5	82	sunny	nil
10.00	7.5	7.5	9.24	27.13	25.5	5	80	cloudy	nil
11.00	35	42.5	10.4	37.53	27.3	3	64	sunny	nil
12.00	13.75	56.25	11	48.53	28.5	10	61	sunny	nil
13.00	132.5	188.75	12.71	61.24	28.5	8	63	sunny	nil
14.00	176.25	365	11.68	72.92	28.9	8	61	sunny	nil
15.00	165	530	11.08	84	27.9	12	63	sunny	nil
16.00	196.25	726.25	10.65	94.65	27.80	4.00	65.00	sunny	nil



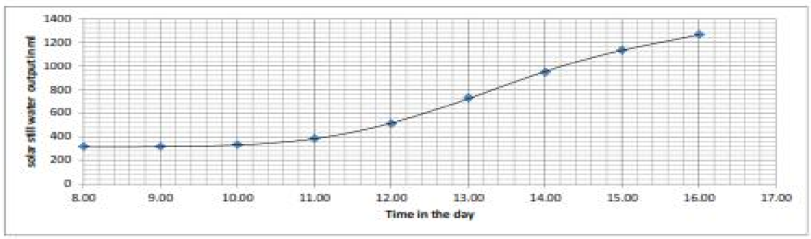


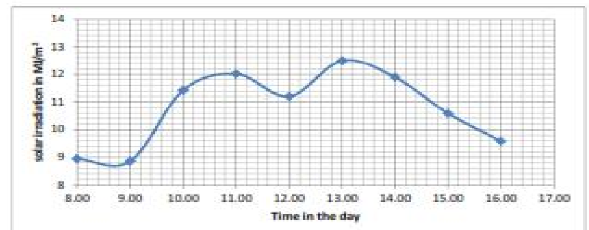


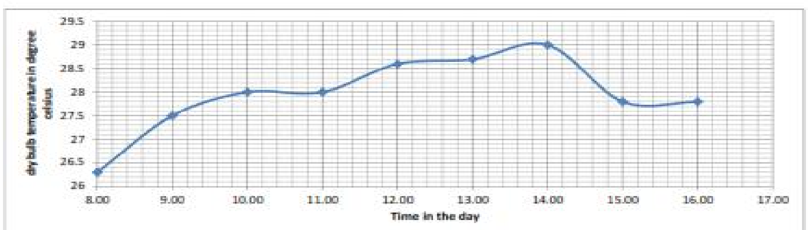


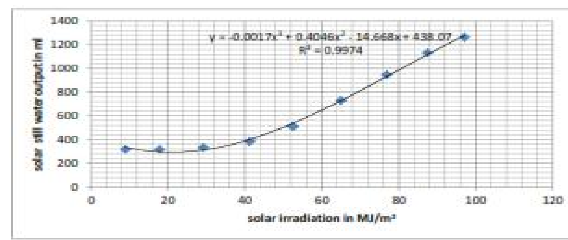
21st september 2016

Time	cumulative solar sill outputs	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfall(mm)
8.00	25.50	318.75	318.75	8.94	8.94	26.3	4	66	sunny	nil
9.00	0.00	0	318.75	8.86	17.8	27.5	8	60	sunny	nil
10.00	1.20	15	333.75	11.43	29.23	28	6	59	sunny	nil
11.00	4.30	53.75	387.5	12.02	41.25	28	8	60	sunny	nil
12.00	9.90	123.75	511.25	11.21	52.46	28.6	3	59	sunny	nil
13.00	17.60	220	731.25	12.5	64.96	28.7	6	56	sunny	nil
14.00	17.30	216.25	947.5	11.9	76.86	29	10	55	sunny	nil
15.00	15.00	187.5	1135	10.59	87.45	27.8	6	62	sunny	nil
16.00	10.50	131.25	1266.25	9.59	97.04	27.8	6	62	sunny	nil





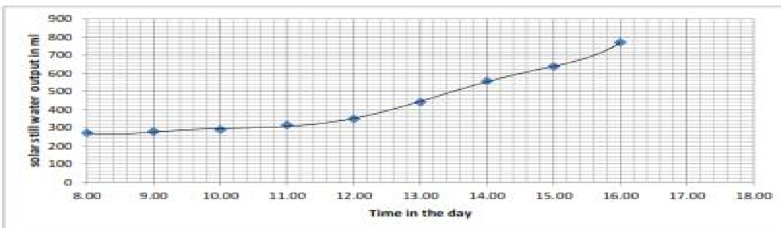


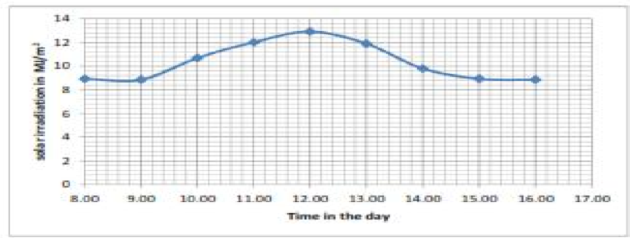


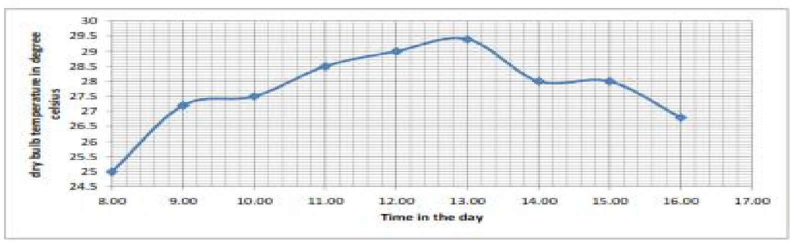
Appendix 20 Data and graphs for various days

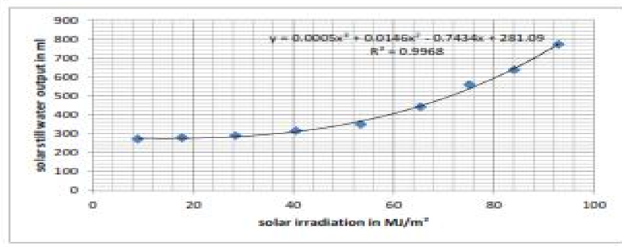
22nd september 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	272	272	8.94	8.94	25	3	79	cloudy	nil
9.00	7	279	8.86	17.8	27.2	6	71	sunny	nil
10.00	10.2	289.2	10.7	28.5	27.5	8	68	sunny	nil
11.00	26	315.2	12.02	40.52	28.5	6	64	sunny	nil
12.00	34	349.2	12.92	53.44	29	10	64	sunny	nil
13.00	93	442.2	11.9	65.34	29.4	12	61	sunny	nil
14.00	116.3	558.5	9.8	75.14	28	4	70	cloudy	nil
15.00	79	637.5	8.94	84.08	28	12	70	cloudy	nil
16.00	133.8	771.3	8.86	92.94	26.8	5	75	cloudy	nil





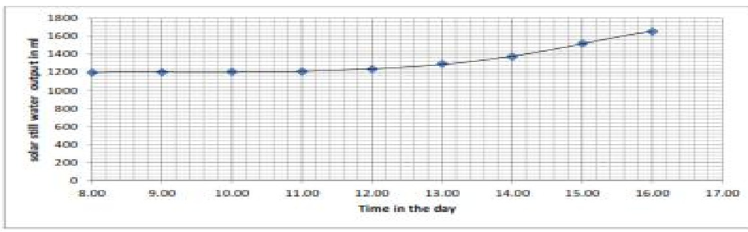


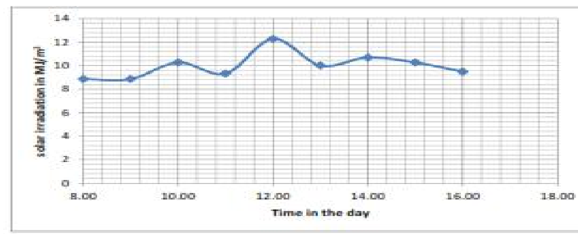


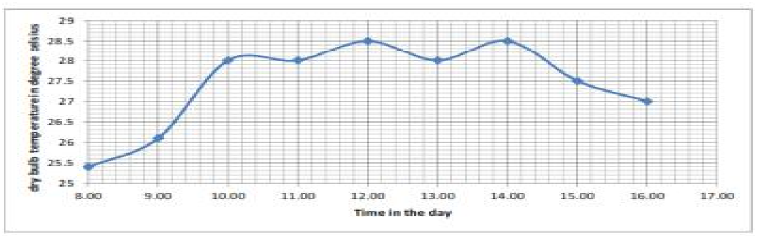
Appendix 20 Data and graphs for various days

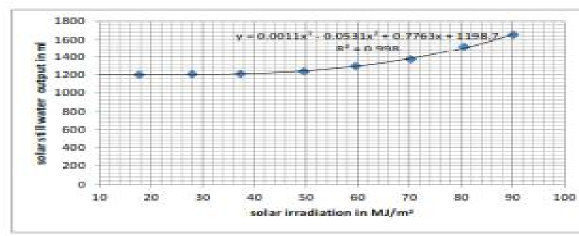
23rd september 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m²)	cumulative solar irradiation(MJ/m²)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	1200	1200	8.86	8.86	25.4	5	84	cloudy	nil
9.00	3	1203	8.86	17.72	26.1	3	79	cloudy	nil
10.00	6	1209	10.27	27.99	28	5	72	partly clo	nil
11.00	2	1211	9.33	37.32	28	8	74	cloudy	nil
12.00	27.5	1238.5	12.28	49.6	28.5	10	63	cloudy	nil
13.00	58	1296.5	10.01	59.61	28	6	70	cloudy	nil
14.00	76.3	1372.8	10.7	70.31	28.5	8	67	sunny	nil
15.00	147.5	1520.3	10.27	80.58	27.5	6	71	sunny	nil
16.00	132.5	1652.8	9.5	90.08	27	3	70	cloudy	nil





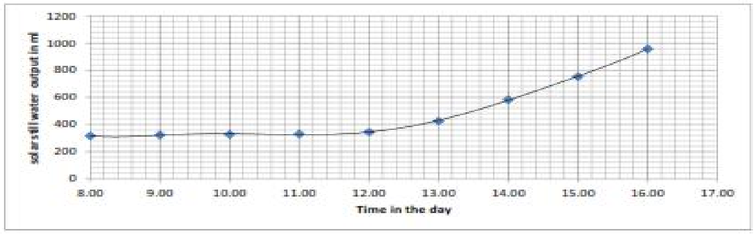


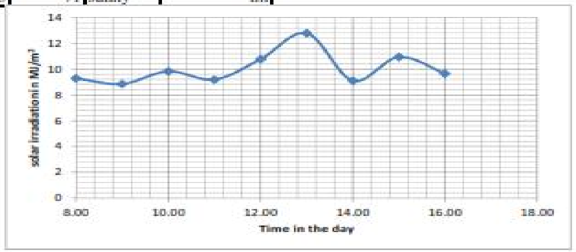


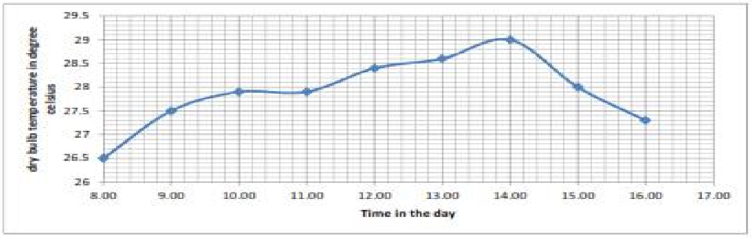
Appendix 20 Data and graphs for various days

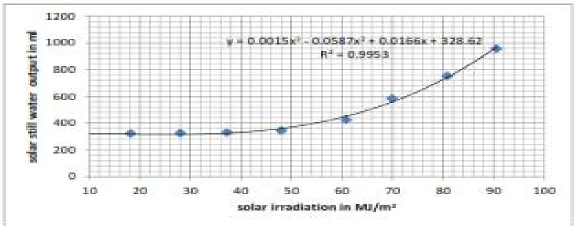
24th september 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	317.5	317.5	9.29	9.29	26.5	5	76	cloudy	nil
9.00	6.3	323.8	8.86	18.15	27.5	6	72	sunny	nil
10.00	4	327.8	9.84	27.99	27.9	3	67	cloudy	nil
11.00	3.5	331.3	9.2	37.19	27.9	5	67	cloudy	nil
12.00	13.8	345.1	10.78	47.97	28.4	6	66	sunny	nil
13.00	81.3	426.4	12.79	60.76	28.6	4	63	sunny	nil
14.00	158	584.4	9.11	69.87	29	4	64	sunny	nil
15.00	170	754.4	10.95	80.82	28	6	67	sunny	nil
16.00	203.8	958.2	9.67	90.49	27.3	3	71	sunny	nil





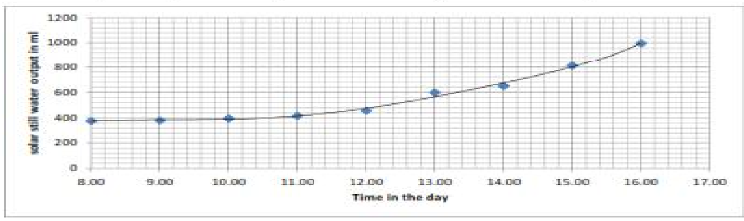


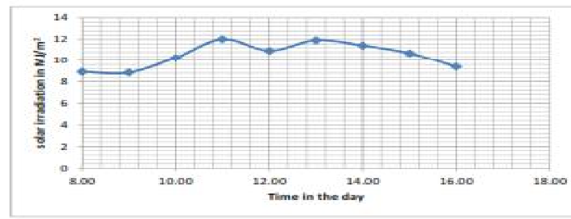


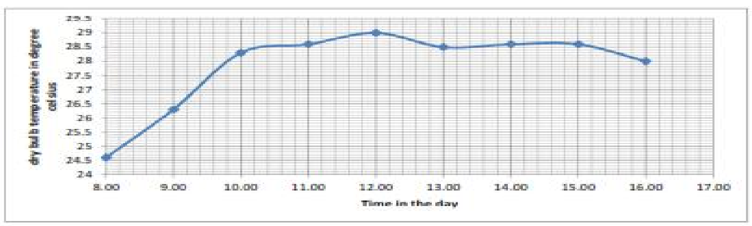
Appendix 20 Data and graphs for various days

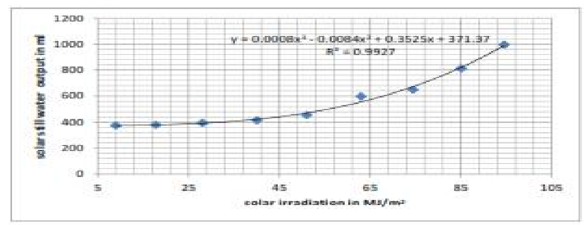
25th september 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m²)	cumulative solar irradiation(MJ/m²)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	375	375	8.94	8.94	24.6	5	91	cloudy	nil
9.00	4	379	8.86	17.8	26.3	4	75	sunny	nil
10.00	17	396	10.27	28.07	28.3	6	63	sunny	nil
11.00	19	415	12.02	40.09	28.6	6	64	sunny	nil
12.00	40	455	10.95	51.04	29	10	60	sunny	nil
13.00	143.8	598.8	11.93	62.97	28.5	8	64	sunny	nil
14.00	52.5	651.3	11.43	74.4	28.6	6	64	sunny	nil
15.00	162	813.3	10.7	85.1	28.6	6	68	sunny	nil
16.00	184.7	998	9.41	94.51	28	3	67	sunny	nil





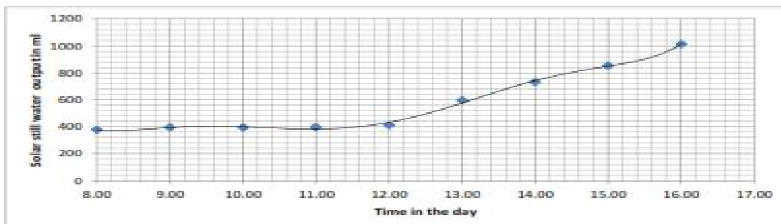


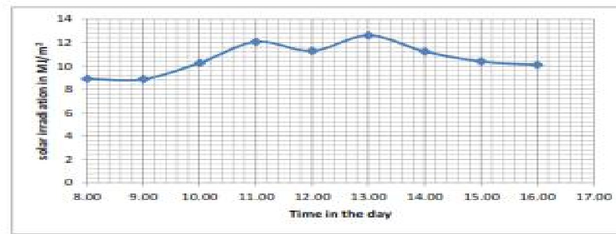


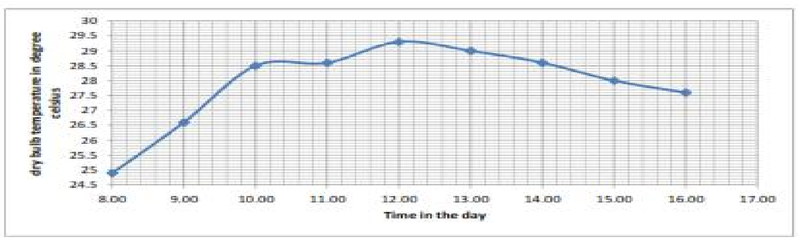
Appendix 20 Data and graphs for various days

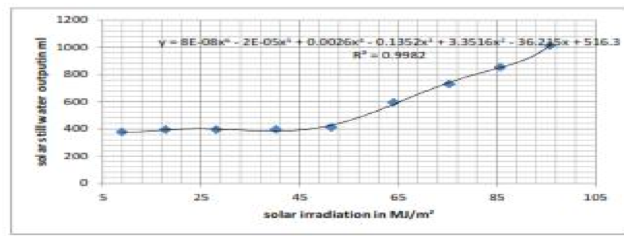
26th september 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m²)	cumulative solar irradiation(MJ/m²)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	379	379	8.9	8.9	24.9	5	92	sunny	nil
9.00	16.3	395.3	8.86	17.76	26.6	3	73	sunny	nil
10.00	0	395.3	10.27	28.03	28.5	3	64	sunny	nil
11.00	2	397.3	12.07	40.1	28.6	6	65	sunny	nil
12.00	15	412.3	11.3	51.4	29.3	12	62	sunny	nil
13.00	184	596.3	12.62	64.02	29	8	61	sunny	nil
14.00	135	731.3	11.25	75.27	28.6	8	60	sunny	nil
15.00	124	855.3	10.4	85.67	28	10	63	sunny	nil
16.00	159	1014.3	10.1	95.77	27.6	4	63	sunny	nil



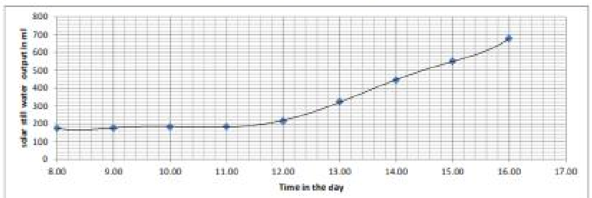


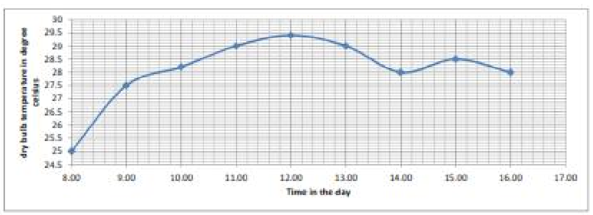


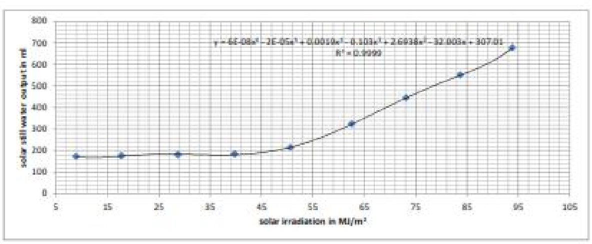


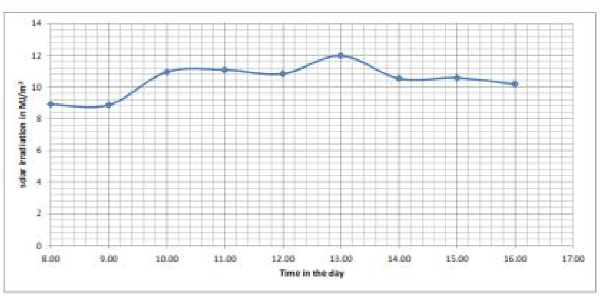
27th september 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	174	174	8.9	8.9	25	5	80	sunny	nil
9.00	2	176	8.86	17.76	27.5	3	70	sunny	nil
10.00	6	182	10.95	28.71	28.2	3	67	sunny	nil
11.00	2	184	11.08	39.79	29	10	62	partly cloudy	nil
12.00	30	214	10.83	50.62	29.4	12	64	partly cloudy	nil
13.00	110	324	11.98	62.6	29	10	64	partly cloudy	nil
14.00	121	445	10.53	73.13	28	5	66	sunny	nil
15.00	105	550	10.57	83.7	28.5	10	67	sunny	nil
16.00	128	678	10.18	93.88	28	4	68	sunny	nil





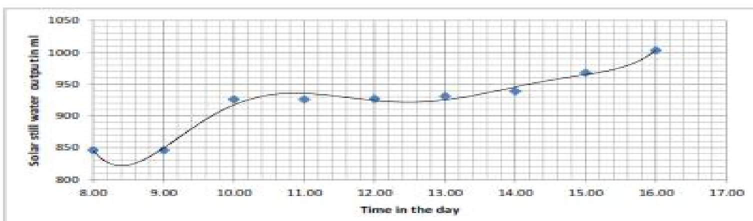


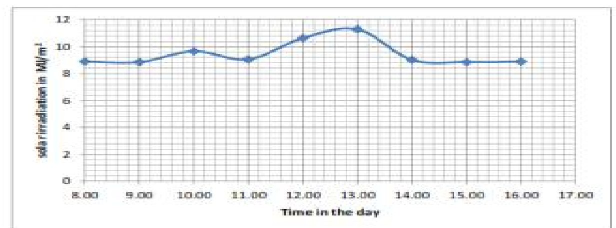


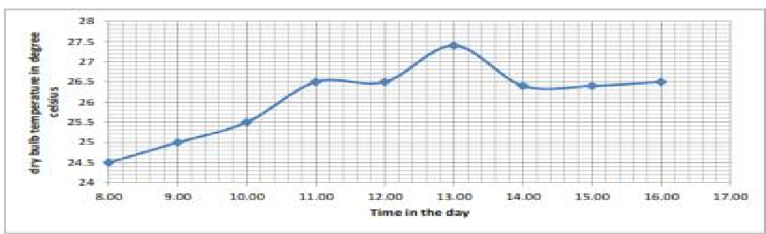
Appendix 20 Data and graphs for various days

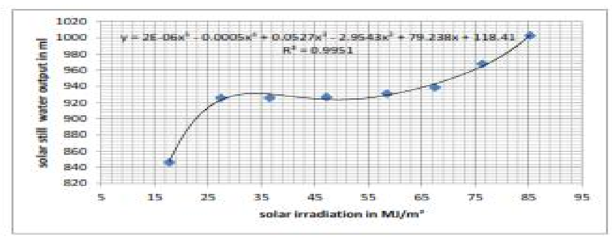
28th september 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	846	846	8.9	8.9	24.5	5	80	cloudy	nil
9.00	0	846	8.86	17.76	25	5	88	cloudy	0.7
10.00	80	926	9.67	27.43	25.5	5	88	cloudy	nil
11.00	0	926	9.07	36.5	26.5	5	85	cloudy	nil
12.00	1	927	10.65	47.15	26.5	4	85	cloudy	nil
13.00	4	931	11.3	58.45	27.4	4	80	cloudy	nil
14.00	8	939	9.03	67.48	26.4	5	85	cloudy	nil
15.00	29	968	8.86	76.34	26.4	5	85	cloudy	3.8
16.00	35	1003	8.9	85.24	26.5	5	85	cloudy	nil





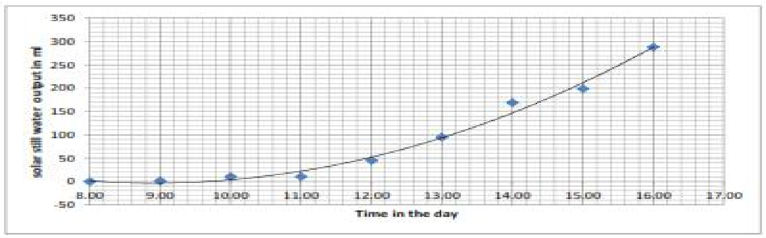


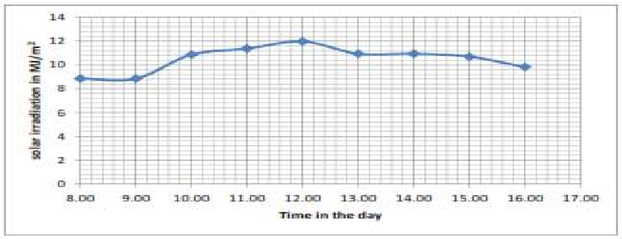


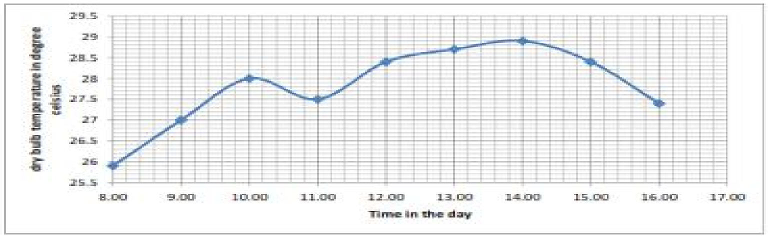
Appendix 20 Data and graphs for various days

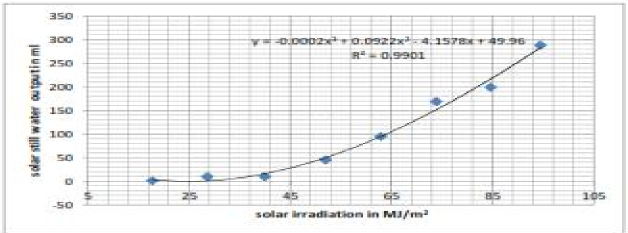
29th september 2016

Time	still output (ml)	cumulative solar sill outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	0	0	8.86	8.86	25.9	5	85	cloudy	nil
9.00	1	1	8.86	17.72	27	4	77	cloudy	2.1
10.00	9	10	10.87	28.59	28	6	74	sunny	nil
11.00	0	10	11.38	39.97	27.5	5	72	sunny	nil
12.00	35	45	11.98	51.95	28.4	10	71	sunny	nil
13.00	50	95	10.95	62.9	28.7	8	69	sunny	nil
14.00	74	169	10.95	73.85	28.9	6	68	sunny	nil
15.00	30	199	10.7	84.55	28.4	8	70	sunny	3.8
16.00	89	288	9.84	94.39	27.4	3	73	sunny	nil





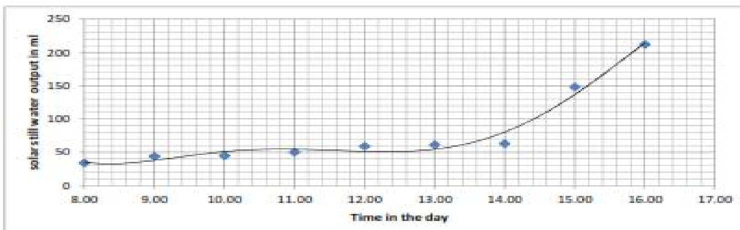


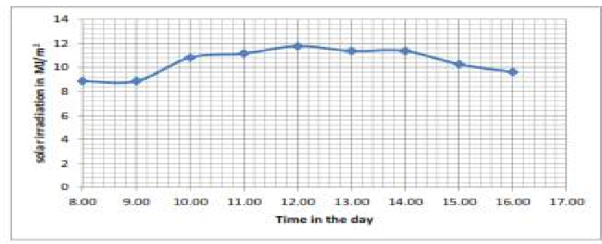


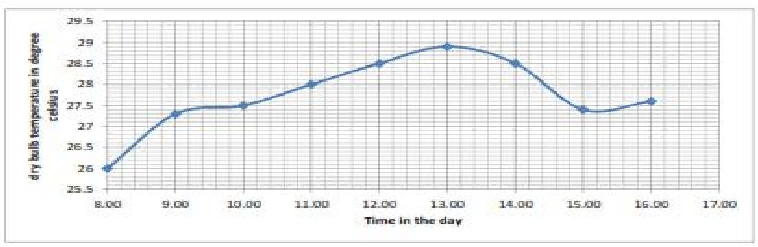
Appendix 20 Data and graphs for various days

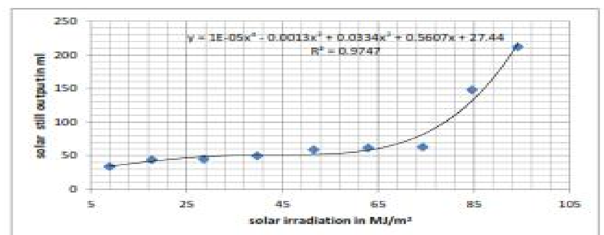
30th september 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	34	34	8.86	8.86	26	5	75	sunny	nil
9.00	10	44	8.86	17.72	27.3	4	66	sunny	nil
10.00	1	45	10.83	28.55	27.5	10	65	sunny	nil
11.00	5	50	11.17	39.72	28	6	64	sunny	nil
12.00	9	59	11.77	51.49	28.5	8	64	sunny	nil
13.00	2.5	61.5	11.38	62.87	28.9	6	60	sunny	nil
14.00	1.5	63	11.38	74.25	28.5	8	64	sunny	nil
15.00	85	148	10.27	84.52	27.4	6	67	sunny	nil
16.00	64	212	9.63	94.15	27.6	4	69	sunny	nil





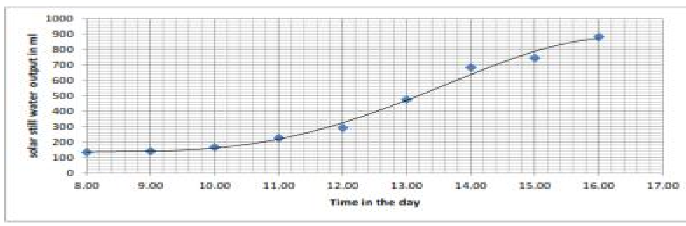


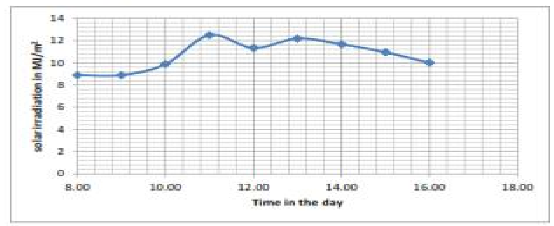


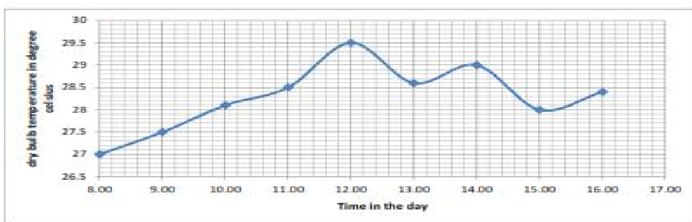
Appendix 20 Data and graphs for various days

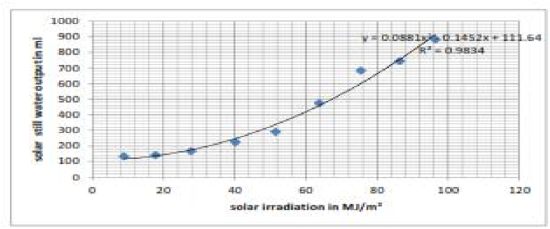
1st october 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	134	134	8.9	8.9	27	4	70	sunny	nil
9.00	7	141	8.9	17.8	27.5	4	67	sunny	nil
10.00	25	166	9.88	27.68	28.1	4	63	sunny	nil
11.00	60	226	12.5	40.18	28.5	10	63	sunny	nil
12.00	66	292	11.34	51.52	29.5	8	56	sunny	nil
13.00	184	476	12.2	63.72	28.6	6	63	sunny	nil
14.00	208	684	11.68	75.4	29	8	55	sunny	nil
15.00	61	745	10.95	86.35	28	4	67	sunny	nil
16.00	139	884	10.01	96.36	28.4	4	64	sunny	nil





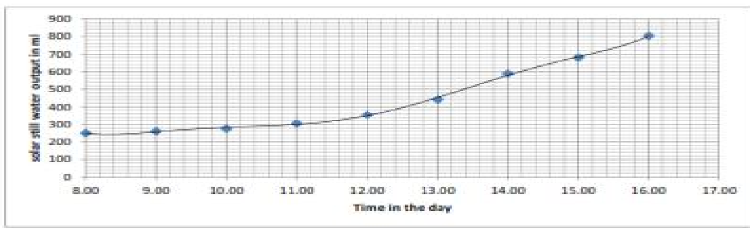


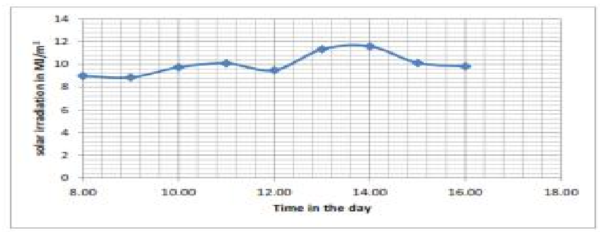


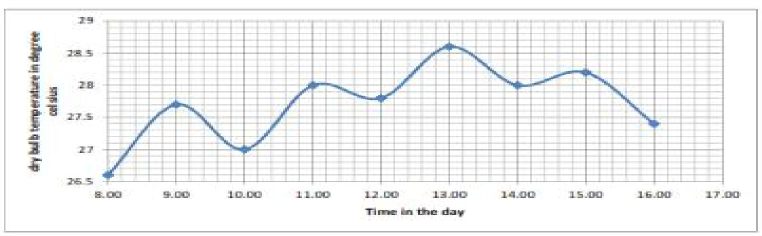
Appendix 20 Data and graphs for various days

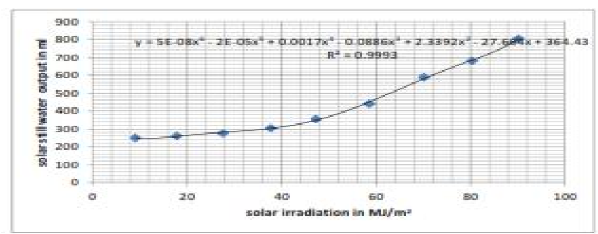
2nd october 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	250	250	8.99	8.99	26.6	4	76	sunny	nil
9.00	11	261	8.86	17.85	27.7	8	72	cloudy	nil
10.00	15	276	9.76	27.61	27	6	72	cloudy	nil
11.00	30	306	10.1	37.71	28	4	70	cloudy	nil
12.00	49	355	9.5	47.21	27.8	6	71	cloudy	nil
13.00	86	441	11.34	58.55	28.6	4	66	sunny	nil
14.00	149	590	11.6	70.15	28	6	68	sunny	nil
15.00	91	681	10.14	80.29	28.2	10	69	sunny	nil
16.00	124	805	9.84	90.13	27.4	6	71	sunny	nil





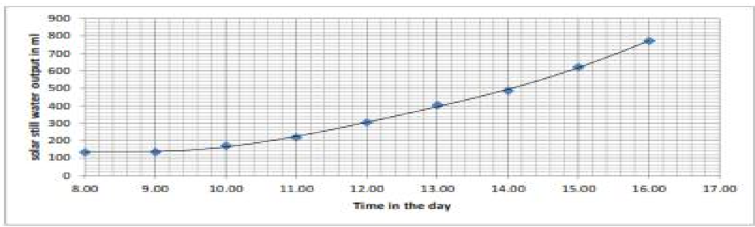


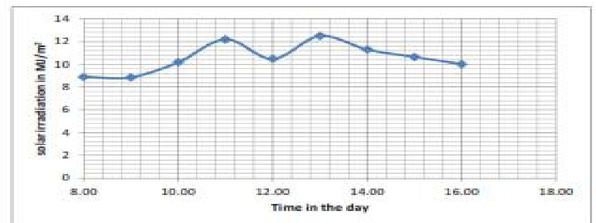


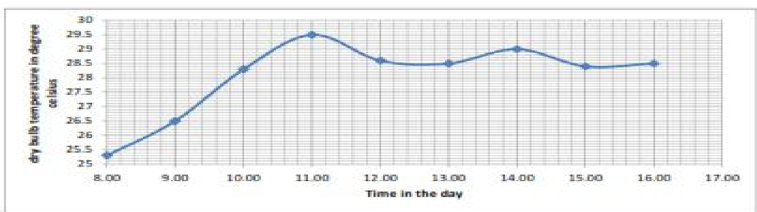
Appendix 20 Data and graphs for various days

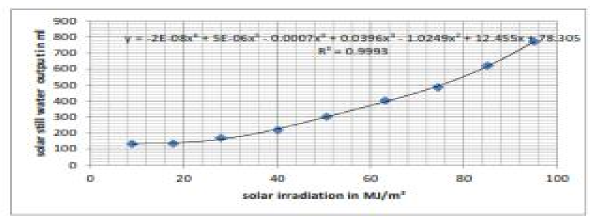
3rd october 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	133	133	8.9	8.9	25.3	5	84	cloudy	nil
9.00	2	135	8.86	17.76	26.5	5	77	sunny	nil
10.00	36	171	10.18	27.94	28.3	4	68	sunny	nil
11.00	48	219	12.2	40.14	29.5	6	65	sunny	nil
12.00	85	304	10.48	50.62	28.6	8	67	sunny	nil
13.00	100	404	12.5	63.12	28.5	6	67	sunny	nil
14.00	82.5	486.5	11.3	74.42	29	4	67	sunny	nil
15.00	136	622.5	10.65	85.07	28.4	10	70	sunny	nil
16.00	150	772.5	10.01	95.08	28.5	6	71	sunny	nil





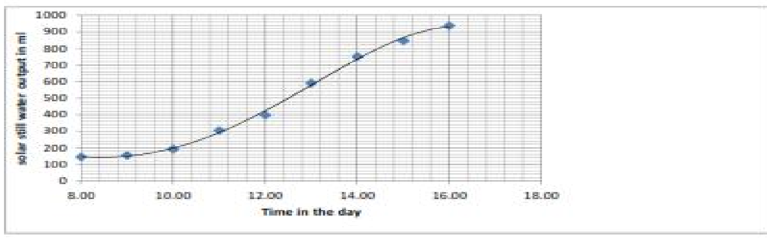


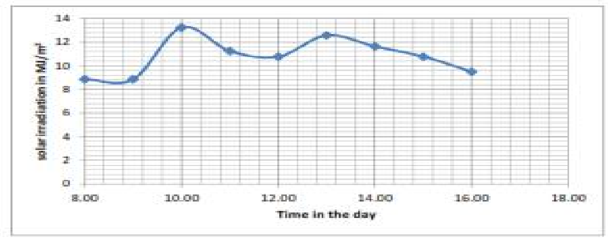


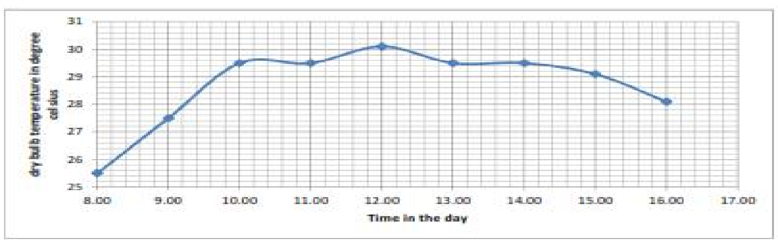
Appendix 20 Data and graphs for various days

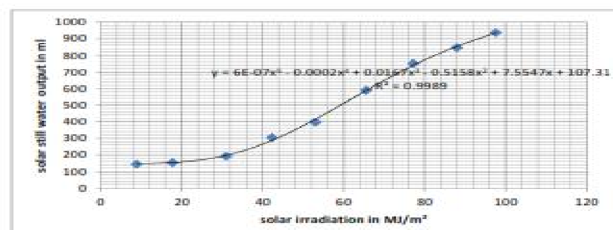
4th october 2016

Time	still output (ml)	cumulative solar still outputs	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	145	145	8.86	8.86	25.5	5	84	cloudy	nil
9.00	10	155	8.86	17.72	27.5	4	70	sunny	nil
10.00	38	193	13.25	30.97	29.5	4	61	sunny	nil
11.00	113	306	11.25	42.22	29.5	5	61	sunny	nil
12.00	92	398	10.78	53	30.1	6	58	sunny	nil
13.00	194	592	12.58	65.58	29.5	3	62	sunny	nil
14.00	160	752	11.64	77.22	29.5	3	61	sunny	nil
15.00	95	847	10.78	88	29.1	10	64	sunny	nil
16.00	91	938	9.5	97.5	28.1	6	68	sunny	nil



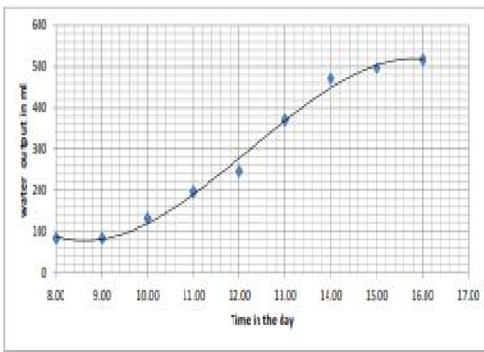


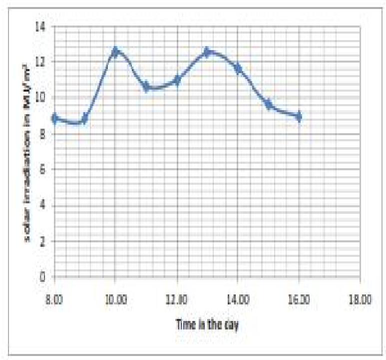


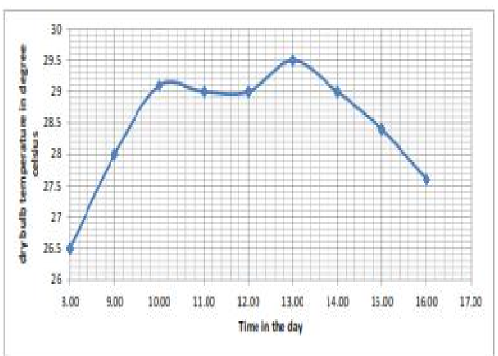


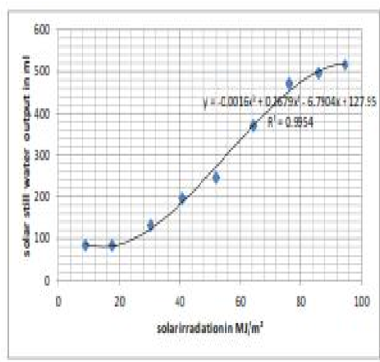
6th October 2016

Time	still output (ml)	cumulative solar still output in ml	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	84	84	8.86	8.86	26.5	10	80	cloucy	nil
9.00	0	84	8.86	17.72	28	8	71	cloucy	nil
10.00	48	132	12.54	30.26	29.1	12	67	sunny	nil
11.00	65	197	10.65	40.91	29	16	58	partly cloucy	nil
12.00	50	247	11	51.91	29	14	65	sunny	nil
13.00	124	371	12.54	64.45	29.5	10	64	sunny	nil
14.00	101	472	11.64	76.09	29	10	64	sunny	nil
15.00	25	497	9.63	85.72	28.4	12	69	cloucy	nil
16.00	20	517	8.94	94.66	27.6	6	70	cloucy	nil





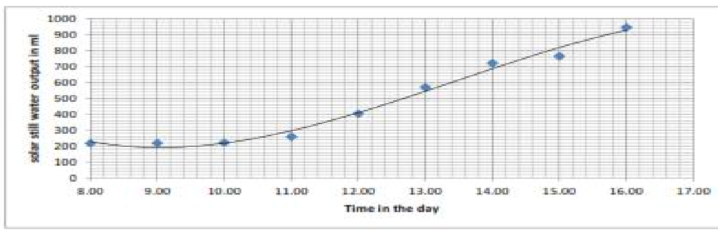


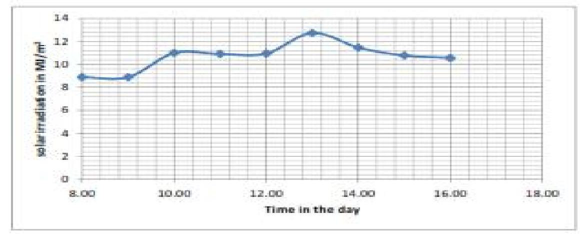


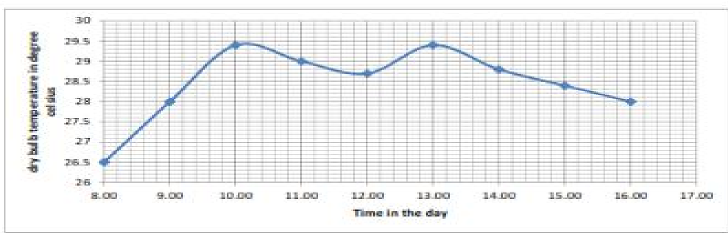
Appendix 20 Data and graphs for various days

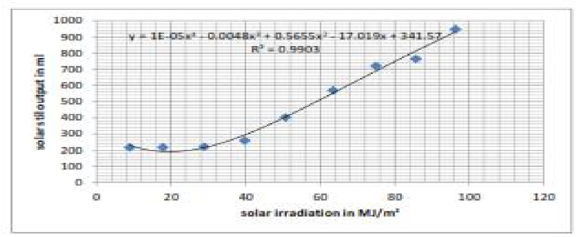
6th October 2016

Time	still output (ml)	cumulative solar still output in ml	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00	218	218	8.9	8.9	26.5	5	73	cloudy	nil
9.00	1	219	8.9	17.8	28	4	63	sunny	nil
10.00	3	222	11	28.8	29.4	5	62	sunny	nil
11.00	38	260	10.91	39.71	29	4	61	sunny	nil
12.00	144	404	10.95	50.66	28.7	4	65	sunny	nil
13.00	167	571	12.75	63.41	29.4	6	60	sunny	nil
14.00	151	722	11.47	74.88	28.8	8	63	sunny	nil
15.00	44	766	10.78	85.66	28.4	6	64	sunny	nil
16.00	182	948	10.57	96.23	28	4	66	sunny	nil





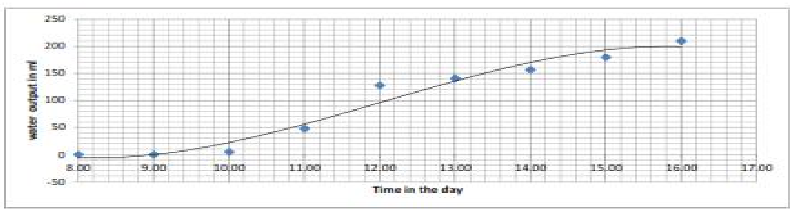


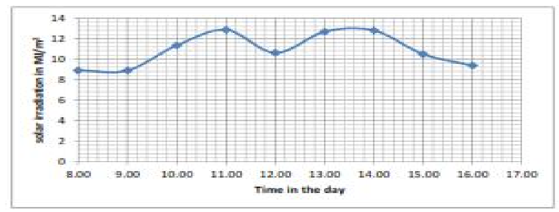


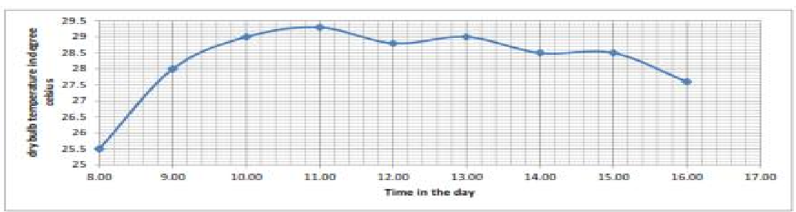
Appendix 20 Data and graphs for various days

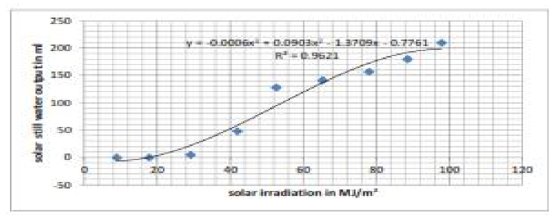
7th october 2016

Time		still output (ml)	cumulative solar still output in ml	solar irradiation(MJ/m^2)	cumulative solar irradiation(MJ/m^2)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
8.00		0	0	8.9	8.9	25.5	5	80	sunny	nil
9.00		0	0	8.9	17.8	28	5	60	sunny	nil
10.00		5	5	11.34	29.14	29	5	60	sunny	nil
11.00		43	48	12.84	41.98	29.3	4	60	sunny	nil
12.00		80	128	10.61	52.59	28.8	4	63	sunny	nil
13.00		13	141	12.67	65.26	29	4	62	sunny	nil
14.00		16	157	12.79	78.05	28.5	6	64	sunny	nil
15.00		23	180	10.48	88.53	28.5	8	65	sunny	nil
16.00		30	210	9.37	97.9	27.6	4	68	sunny	nil





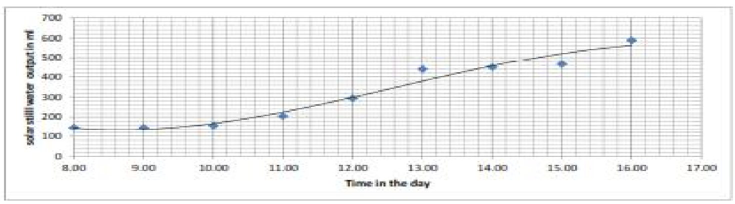


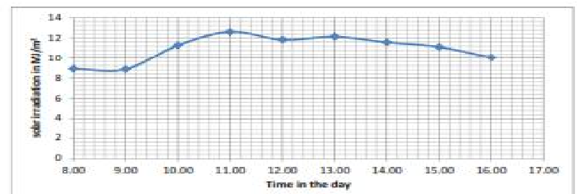


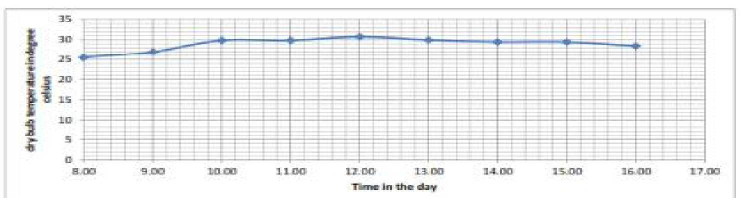
Appendix 20 Data and graphs for various days

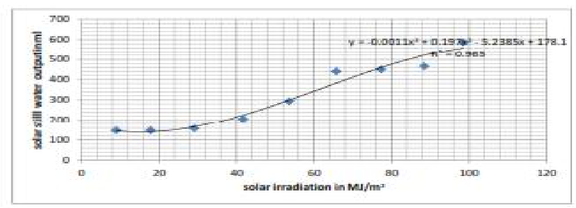
8th october 2018

Time		still output (ml)	cumulative solar still output in ml	solar irradiation(MJ/m²)	cumulative solar irradiation(MJ/m²)	dry bulb temperature	wind velocity	relative humidity	weather - sky	rainfull(mm)
7.00										
8.00		148	148	8.9	8.9	25.5	5	83	sunny	nill
9.00		0	148	8.86	17.76	27	5	76	sunny	nill
10.00		10	158	11.3	29.06	29.9	3	54	sunny	nill
11.00		48	206	12.62	41.68	29.9	3	55	sunny	nill
12.00		89	295	11.85	52.53	30.8	6	59	sunny	nill
13.00		146	441	12.15	65.68	30	8	62	sunny	nill
14.00		10	451	11.6	77.28	29.5	6	65	sunny	nill
15.00		15	466	11.13	88.41	29.5	6	67	sunny	nill
16.00		122	588	10.06	98.47	28.5	4	70	sunny	nill









Appendix 20 Data and graphs for various days

9th October 2016

Time	dry bulb temperature	wind velocity	relative humidity	weather -sky	rainfull(mm)	still output (ml)	cumulative solar still output in ml	solar irradiation(MJ/m2)	cumulative solar irradiation(MJ/m2)
8.00	24.5	5	91	cloudy	nil	130	130	8.86	8.86
9.00	26.5	5	80	cloudy	nil	0	130	8.86	17.72
10.00	27.5	5	76	cloudy	nil	0	130	9.37	27.00
11.00	27.4	3	71	cloudy	nil	20	150	9.76	36.85
12.00	29.6	6	61	sunny	nil	30	180	9.88	46.73
13.00	29.6	8	61	sunny	nil	34	214	13.09	59.82
14.00	29.4	4	66	sunny	nil	5	219	12.41	72.23
15.00	28.9	8	65	sunny	nil	5	224	10.95	83.18
16.00	28.4	3	68	sunny	nil	4	228	10.4	93.58